Universitat de Lleida

Escola Politècnica Superior

Màster en Ciències Aplicades a l'Enginyeria

Treball de final de màster

Numerical analysis of including phase change material in a domestic hot water cylinder

Autor/a: Alvaro de Gracia Cuesta
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Summary

1 Introduction

A domestic water tank is a widely used device to provide hot water for sanitary or cooking purposes being an important source of energy consumption [1]. The domestic electrical hot water cylinder used in this paper incorporates encapsulated phase change material (PCM) placed in 57 vertical pipes. The use of PCM increases the thermal energy storage capacity of the cylinder and allows the use of low cost electricity during low peak periods. The operational mode of the system is based on heating the water and spending an extra amount of energy to melt the phase change material during night. After a first discharge of hot water, the extra amount of energy stored in the phase change material will be transfered to the recently introduced cold water increasing its temperature without using electricity.

In this project a mathematical model was developed to describe heat transfer during heat charge and water discharge in a typical domestic hot water cylinder previously studied experimentally by Farid et al. [2]. The already measured experimental data prove the efficiency of the use of PCM in these systems and are used to validate the developed code for numerical simulation using finite differences method.

The objective of this project is to optimize the PCM distribution inside the hot water cylinder under different scenarios of hot water demand. A parametrical study with different PVC tubes containing the PCM will be carried out following experimental model validation.

2 Brief survey on related work

Many researchers have analyzed the thermal performance of a domestic hot water tank during the last years. One of the main topics that has been studied is the stratification of the water inside the tanks but most of the works have addressed solar heating applications. Ievers and Lin [1] used seven three-dimensional numerical models to evaluate the level of thermal stratification. Abdoly and Rapp [3] studied theoretically the degradation of heat in stratified thermo-cline on a conductive model. Hahne and Chen [4] evaluated numerically the thermal stratification in a cylindrical hot water store during the charging process under adiabatic thermal boundary conditions. The temperature stratification in hot water storage systems (mainly in plastic cylindrical vessels), were studied experimentally by Lavan and Thompson [5]. A two-dimensional model which was simplified using pure conduction was employed in the work of Ismail et al. [6]. Cruickshank and Harrison [7] carried out different tests on a domestic hot water tank and included a cool-down test and a heat diffusion test sequence. In addition, Buzás et al. [8] dealt with the modelling and simulation aspects of the main components of a solar hot water system.

Thermal energy storage has become an important issue in the global energetic scene and has been widely used to increase the energetic efficiency of different applications. Phase change materials (PCM) have been applied to increase the thermal energy storage capacity of different systems [9, 10]. The major advantages of using PCM in energy storage systems are their large heat storage capacity and their isothermal behaviour during charging and discharging processes [11]. In several countries, the cost of the electricity is cheaper during night. Hence, the inclusion of PCM inside a domestic hot water tank could be successful in reducing the electricity peak loads using night storage.

The use of PCM in different applications have been analyzed and numerically simulated. Padmanabhan and Murthy [12] developed a conductive numerical model, solved by finite difference method to describe the phase change process occurring in a cylindrical tube. Costa et al. [13] has analyzed the use of latent heat storage systems with and without fins for space heating. Farid et al [14] used an effective thermal conductivity to address the natural convection during the melting and solidification process of PCM in a vertical cylinder.

Different numerical models related to water storage tanks with and without PCM have been presented in the literature. Conductive models were used [5, 6, 15] and in many cases the results were in a good agreement with the measurements. Moreover, it was observed that there were virtually no temperature gradients in the horizontal direction in water [7]. Cabeza et al. [16] studied experimentally the addition of PCM module at the top of a hot-water storage tank having thermal stratification. Furthermore, a new TRNSYS type was developed for the same system and validated by Ibáñez et al. [17] demonstrating that the inclusion of PCM (granular PCM-graphite compound) modules in several cylinders increases the thermal energy storage capacity of water tanks for domestic hot-water supply.

3 Methodology

3.1 Description of the system

The hot water cylinder has an inner diameter of 0.474 m and is 1.02 m long. Its water holding capacity was reduced from 180 L to 123 L because of the inclusion of the 57

PVC tubes that contain the PCM (0.75 m long and 0.04 m diameter). The domestic hot water cylinder was heated from the bottom of the cylinder with 3 kW electrical heater, which is controlled by a thermostat. Cold water enters from the bottom of the water cylinder while the hot water leaves from the top. Seven thermocouples were placed inside the tank to record the temperature distribution within the cylinder in the vertical plane. The system is insulated with 5 cm polyurethane. A sketch of the hot water cylinder with PCM is shown in Figure 1.

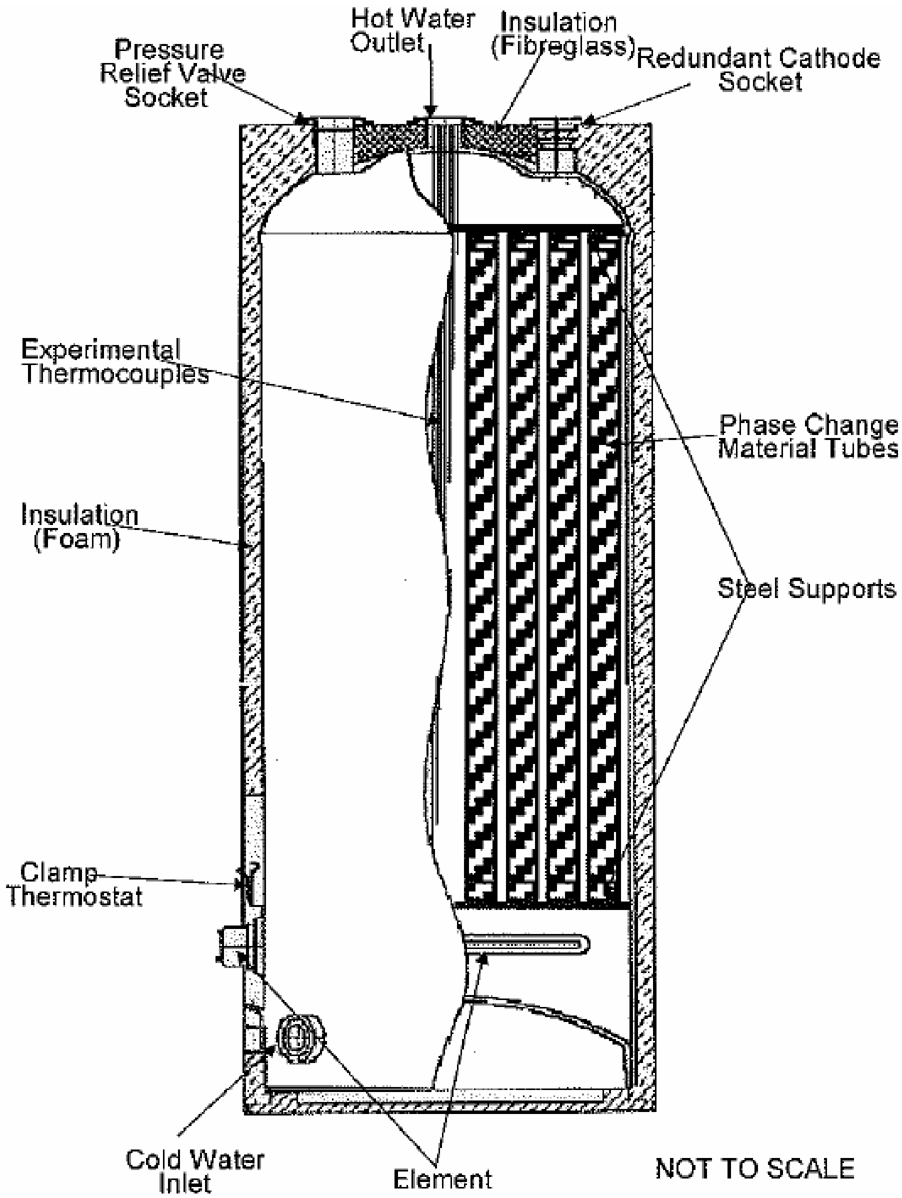

Figure 1. Hot water cylinder with inner PVC tubes containing PCM [2].

3.2 Numeral modelling

The energy equation during electrical heat charge (Eq.1) and water discharges (Eq.2) was solved using a fully implicit finite difference method of solution in the cylindrical coordinates system (Figure 2).

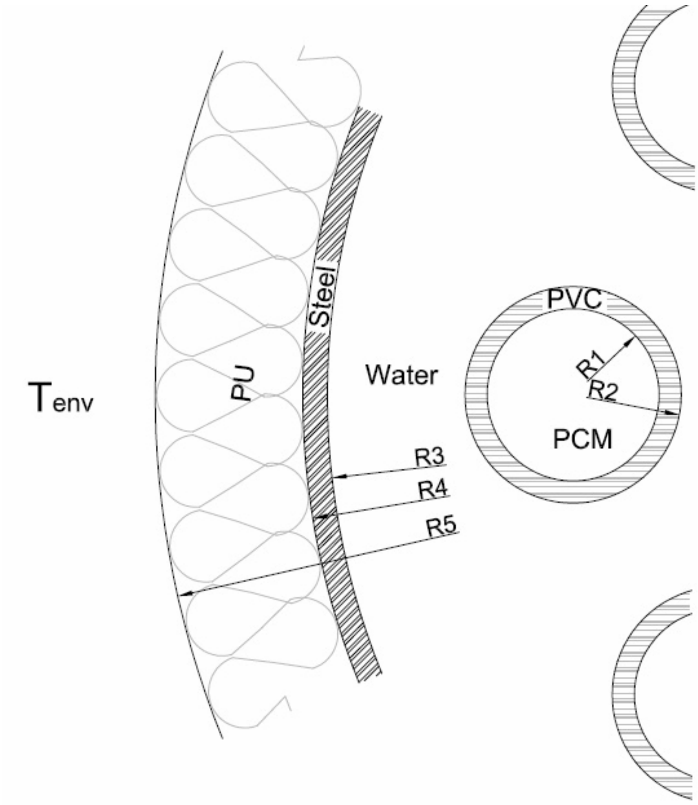

Figure 2. Sketch of the modelled system.

Heat transfer in PCM, PVC tubes, water during electrical charge, and insulation is governed by the heat conduction equation:

$$\frac{\partial H}{\partial t} = k\frac{\partial^2 T}{\partial r^2} \qquad \text{(Eq.1)}$$

Heat transfer during water discharge is governed by the following equation:

$$\frac{\partial H}{\partial t} + v_y\frac{\partial H}{\partial y} = k\left(\frac{\partial^2 T}{\partial r^2} + \frac{\partial^2 T}{\partial y^2}\right) \qquad \text{(Eq.2)}$$

The set of governing equations (1)-(2) is completed by the following initial and boundary conditions:

(i)	t = 0	$T = T_0$	(Eq.3)
(ii)	r = 0	$\frac{\partial T}{\partial r} = 0$	(Eq.4)
(iii)	r = R_1	$T_{PCM} = T_{PVC}$	(Eq.5)
(iv)	r = R_2	$-k_{PVC}\frac{\partial T}{\partial r} = h_1\cdot(T_{R2} - T_w)$	(Eq.6)
(v)	r = R_3	$h_2\cdot(T_w - T_{R3}) = -k_{steel}\frac{\partial T}{\partial r}$	(Eq.7)
(vi)	r = R_4	$T_{steel} = T_{PU}$	(Eq.8)
(vii)	r = R_5	$-k_{PU}\frac{\partial T}{\partial r} = h_3\cdot(T_{R3} - T_{env})$	(Eq.9)
(viii)	r > R_5	$T_{env} = 21^{o} C$	(Eq.10)

The finite difference equations are obtained by discretizing equations (1) and (2) over each control volume [7] (Figure 3), obtaining Eq.11.

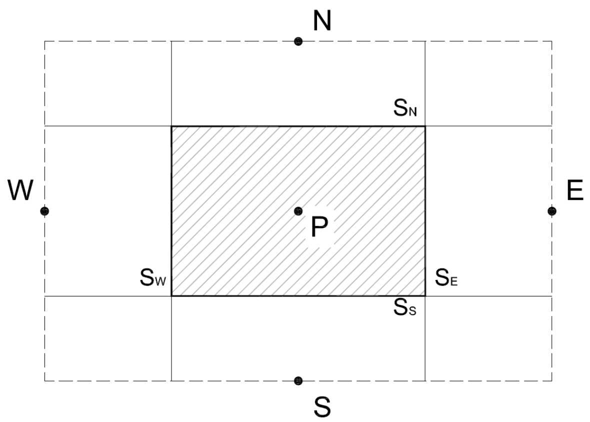

Figure 3. Two-dimensional domain

$$a\cdot(T_P^{n+1} - T_P^{n}) =$$
$$b\cdot(T_P^{n+1} - T_W^{n+1}) + c\cdot(T_P^{n+1} - T_S^{n+1}) - d\cdot(T_p^{n+1} - T_N^{n+1}) - e\cdot(T_p^{n+1} - T_E^{n+1}) + \dot{q} + \dot{m}\cdot C_p\cdot(T_P^{n+1} - T_S^{n+1})$$
(Eq.11)

Where:

a is the rate of heat accumulation in the node P . $a = \dfrac{\rho_P \cdot Cp_P \cdot V_P}{\Delta\tau}$ (Eq.12)

b, c, d and e constants refer to the rate at that heat is transferred in the radius (b and e) and vertical (c and d) direction.

$b = \dfrac{k_W \cdot S_W}{\Delta r}$, $c = \dfrac{k_S \cdot S_S}{\Delta y}$, $d = \dfrac{k_N \cdot S_N}{\Delta y}$ and $e = \dfrac{k_E \cdot S_E}{\Delta r}$ when conduction between nodes

$b = h \cdot S_W$, $c = h \cdot S_S$, $d = h \cdot S_N$ and $e = h \cdot S_E$ when convective heat transfer between nodes.

$\dot{q}$ is the heat generated by the electrical heater, and $\dot{m} \cdot C_p \cdot \left(T_P^{n+1} - T_S^{n+1}\right)$ accounts for the convective term of the energy equation when water is pumped from the system.

The following assumptions have been made to simplify the analysis:

(i) In the available literature it was observed that there were virtually no temperature gradients in the horizontal direction in water [7]. Hence, one single node in the radius direction is used for the water.

(ii) The heat transfer inside the water tank during the electrical charge was described assuming one-dimensional conditions in the radius direction because it is heated from below, since previous experimental measurements show no stratification in the tank [2].

(iii) For water discharges one-dimensional and two-dimensional simulations have been used to simulate the thermal behaviour of the tank (fully mixed flow and plug flow).

(iv) The mixing of the water after discharges is limited by the thermal conductivity of water between the vertical nodes. In reality heat transferred to the water from the PCM could create a natural convection effect and increase the mixing of the water, while on the other hand, the stratification inside the tank reduces the extent of mixing.

(v) The PCM is homogeneous and isotropic.

(vi) The latent heat effect of PCM (hydrated salts TH58) is addressed using effective heat capacity as function of temperature.

(vii) Natural convection was assumed to control heat transfer between the water and the PCM even during water discharges because of the extremely low velocity of the water in the vertical direction ($v \approx 0.04$ m/min, $\mathrm{Re} \approx 200$).

Empirical correlations of Nusselt number were used to calculate the different convective heat transfer coefficients..

- Heat transfer coefficients between PVC tubes and water (h_1), and between the hot water cylinder and the environment (h_3). $\overline{Nu} = C \cdot (Gr \cdot \mathrm{Pr})^m$. C=0.59 and m=0.25. [18]
- Heat transfer coefficient between water and the tank wall (h_2). $\overline{Nu} = C \cdot (Gr \cdot \mathrm{Pr})^m \cdot K$. C=0.8, m=0.25 and $K = \left[1 + \left(1 + \frac{1}{\sqrt{\mathrm{Pr}}}\right)^2\right]^{-1/4}$ [19]
- Heat transfer coefficient between the top surface of the cylinder and the environment(h_5). $\overline{Nu} = C \cdot (Gr \cdot \mathrm{Pr})^m$. C=0.54 and m=0.25. [19]
- Heat transfer coefficient between the bottom surface of the cylinder and the environment(h_4). $\overline{Nu} = C \cdot (Gr \cdot \mathrm{Pr})^m$. C=0.27 and m=0.25. [19]

In the model the number of nodes taken in radial direction were: 10 nodes in the PCM, 5 for the PVC inner tubes, 3 for the steel envelope of the tank and 8 for the insulation foam. For the two-dimensional conditions, 70 nodes in the y-direction were used. The system of algebraic linear equations extracted from the finite differences method were solved using Gauss Seidel iterative method with a time step of 1 second. The solution was found to be mesh-independent based on the above nodes selection.

The physical properties of the materials used in the model are detailed in Table 1.

Table 1. List of physical properties used in the model.

Material	Physical properties	
PVC	ρ	1100 kg/m^3
	C_p	880 J/kg·K
	K	0.12 W/m·K
PCM	ρ_s	1400 kg/m^3
	Cp_s	2880 J/kg·K
	K_s	0.54 W/m·K
	P_L	1290 kg/m^3
	Cp_L	4190 J/kg·K
	K_L	1.09 W/m·K
	λ	185.13 kJ/kg
	T of fusion	57 - 61ºC
Steel	ρ	7901 kg/m^3
	C_p	481 J/kg·K
	K	15.17 W/m·K
Polyurethane	ρ	35 kg/m^3
	C_p	1000 J/kg·K
	K	0.028 W/m·K

3.3 Code validation with experimental data

Experimental data was used to test the accuracy of the numerical solutions and validate the model. The following experiments were simulated and compared against the already measured experimental data:

(i) Electrical heat charge without PCM inside the tank, where the water temperature was increased from 18ºC up to 66ºC. When the temperature reached the set point (66ºC) the electrical element was switched off, which caused the water to cool down because of heat losses to the ambient (21ºC). The thermostat was programmed to keep the water at a set point between 66ºC and 62ºC.

(ii) Electrical heat charge with PCM inside the tank. In this experiment the water temperature was heated from 22ºC up to 70ºC. In this experiment the water temperature was set between 70ºC and 67.5ºC.

(iii) Water discharge with PCM inside the tank. In this experiment water was pumped from the hot water cylinder until its temperature is lower than 45ºC. The PCM during its solidification process, heats up the tap water pumped from below at 14.5ºC. This experiment was simulated using one-dimensional and two-dimensional models in order to compare the mixed flow and plug flow assumptions.

Furthermore, an experiment of full discharge of the tank (water temperature is initially at 80ºC and is pumped with a fixed rate of 7.5 L/min until it decreases to the inlet cold water temperature) were used to compare the two numerical models describing the water discharge (mixed flow and plug flow).

3.4 Description of the different scenarios of energy demand

Once the model has been validated experimentally, a parametric study will be used to optimize the way PCM could be used in future design of hot water cylinders. The different cases considered in this parametric study are described in Table 2 (note that case 5 describes the measured system). The volume of water was kept the same in all cases (123 L). However, since standard PVC tubes were used with different diameter and wall, the amount of PCM was not exactly the same in each case.

Table 2. Parametric analysis with same amount of water inside the tank.

	Outer diameter of the PVC tubes (mm)	Thickness of the PVC tubes (mm)	Volume of PCM (L)	Number of PVC tubes
Case 0	-	-	0	0
Case 1	16	2.05	29.70	356
Case 2	20	2.25	32.27	228
Case 3	25	2.55	34.06	146
Case 4	32	2.75	36.82	89
Case 5	**40**	**2.95**	**39.04**	**57**
Case 6	50	3.20	40.31	36
Case 7	63	3.45	42.64	23
Case 8	80	3.90	43.00	14

The discharge demand from the system was assumed to be 0.2 kg/s of water at the comfort temperature (37ºC), as obtained from mixing of the water pumped from the tank and from the tap at 14.5ºC. Hence, the mass flow rate pumped from the tank is calculated using the following enthalpy balance:

$$\dot{m}_{tank} = \dot{m}_{demand} \cdot \left(\frac{T_{confort} - T_{tap}}{T_{tank} - T_{tap}} \right) \qquad \text{(Eq.13)}$$

Different scenarios of demand will be simulated using the already validated model, which are the following:

(i) Scenario 1: Water discharges until outlet water temperature reaches 37ºC. First discharge at t=0 and second discharge at t=180 min.

(ii) Scenario 2: Water discharges until outlet water temperature reaches 37ºC. First discharge at t=0 and second discharge at t=360 min.

(iii) Scenario 3: Seven water discharges of 10 minutes each at different times of 0, 60, 120, 180, 240, 300, 360 min.

4 Results analysis

4.1 Code validation

4.1.1 Electrical heat charge with and without PCM

The numerical results extracted from the model are compared with the measured experimental data [2]. Figure 4 shows the measured and predicted water temperatures during electrical heat charge of the tank without PCM. The model demonstrates good agreement with the measurements not only in the time needed to reach the set point (210 min), but also in the time at which the water temperature reaches the lower set point (1010 min), due to heat losses. The similarity between numerical results and the experimental data reflects the success of the model in predicting the true performance of the hot water cylinder, including the heat losses to the environment, which determine the period of the heating cycle shown in Figure 4.

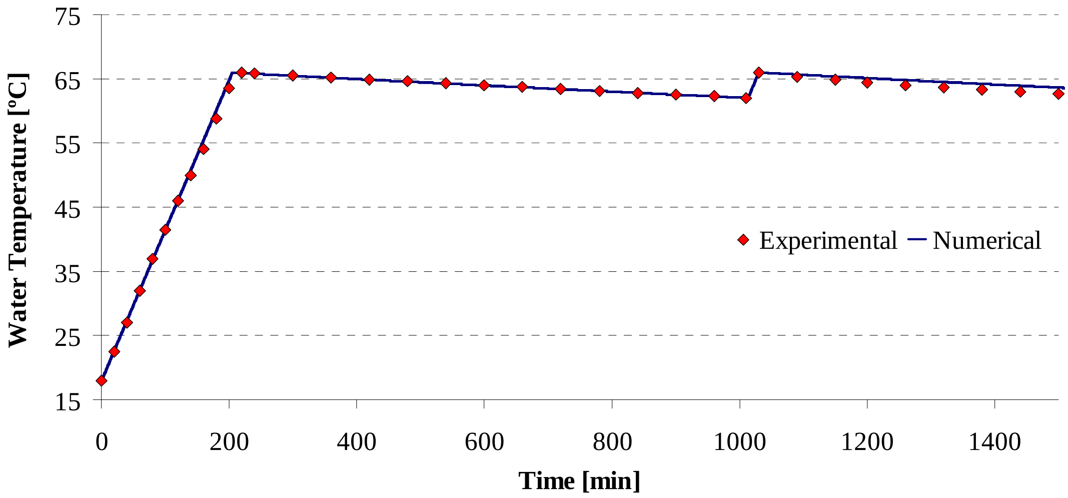

Figure 4. Model validation of electrical charge test without PCM

Figure 5 shows the corresponding situation when PCM was used. Both numerical and experimental temperature ramps during the electrical heating are affected by the inclusion of PCM, being flattened when melting process of PCM occurs. Once this ramp achieves the set point (70ºC), the thermostat switches off the element and the water temperature drops fast by heating the PCM in addition to the heat losses. This is shown by both the numerical simulation and the experiment during the period from 220 to 360 minutes when the PCM is fully melted. The model also shows good agreement with the experimental data after all the PCM is melted, when the period of the heating cycle is increased as shown in Figure 5. The excellent agreement between predicted and measured water temperatures is a good support to the model and the empirical correlation used to predict the different heat transfer coefficients.

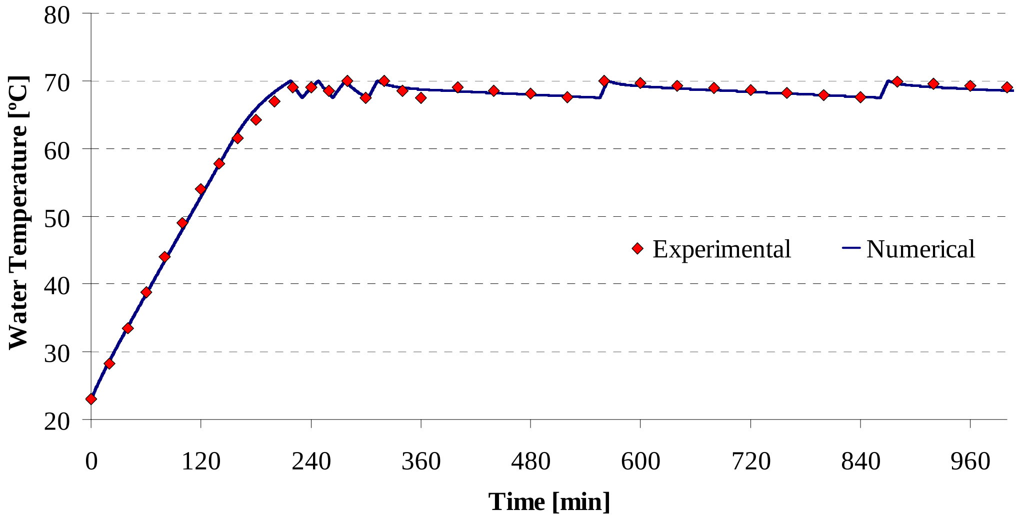

Figure 5. Model validation of electrical charge test with PCM

4.1.2 Water discharge in the tank including PCM

The numerically predicted water discharge temperature using the mixed flow and plug flow models is compared with the experimental data in Figure 6 and Figure 7. The mixed flow model discharges hot water during 20 minutes, while the plug flow model does it during only 15 minutes. The measured total time of water discharge was 18 minutes, lying between these two extreme conditions.

Once the discharges have finished, the PCM heats up the water in both mixed and plug flow models, presenting a good agreement with the experimental data. As it was previously said, the experimental water temperature profiles along the vertical plane were measured. These water temperatures do not show stratification inside the tank after the heat stored by the PCM has been released to the water; hence some mixing must have occurred during the experiment. Five from the seven thermocouples measured the same temperature indicating complete mixing at the top of the tank. The mixed flow model presents the same water temperature than the measured (53.5ºC) while the plug flow model shows higher and lower temperatures depending on the position in the vertical axis, predicting the effect of water flow inside the tank.

The experimental water discharge lies between the numerical results of the two ideal models (fully mixed and plug flow models). However, the plug flow model describes the situation more accurate, since it can predict the estratification ocurring during the period after water discharge.

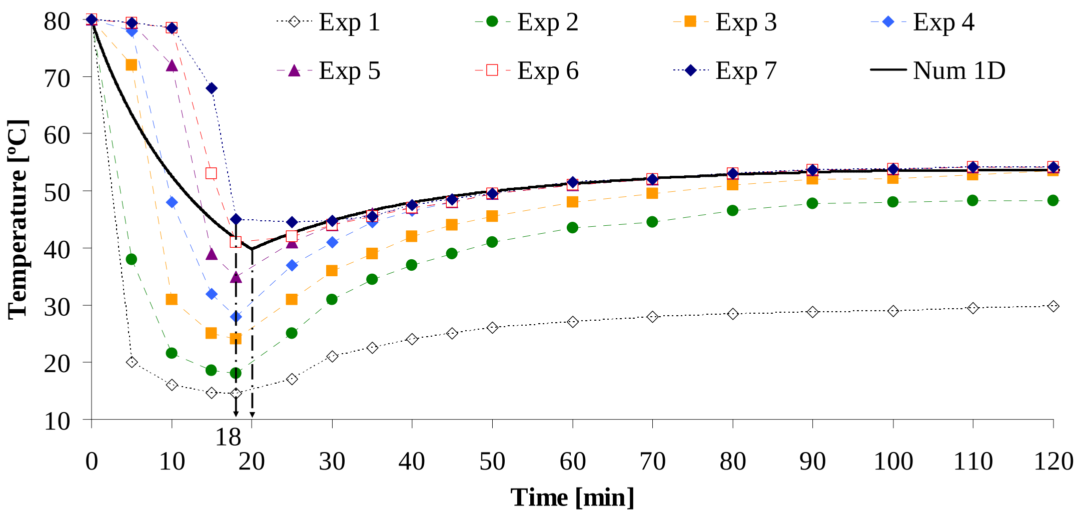

Figure 6. One-dimensional model validation of water discharge test. Fully mixed flow.

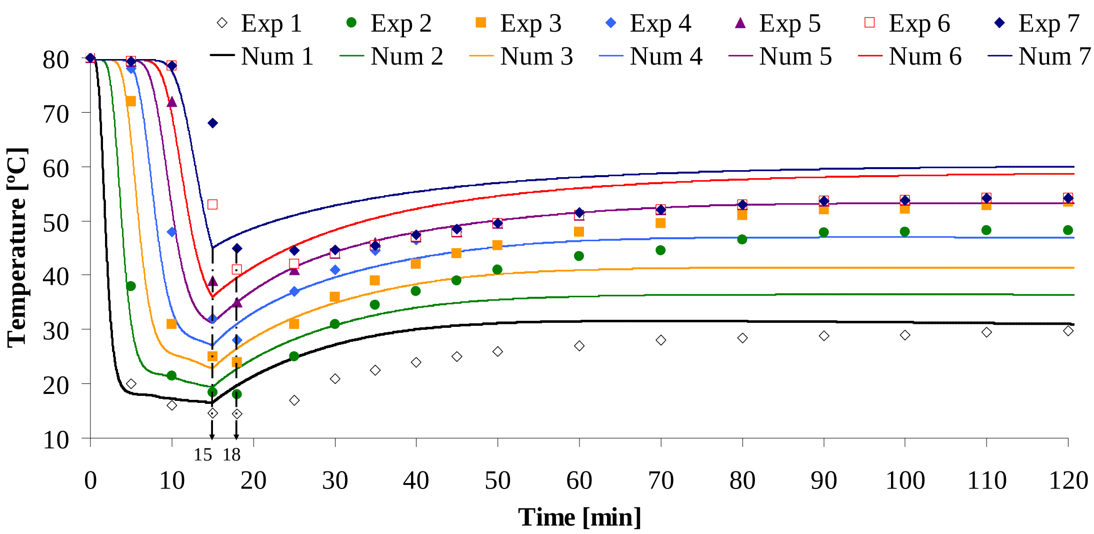

Figure 7. Two-dimensional model validation of water discharge test. Plug flow.

The rates of thermal energy discharged from the tanks with and without PCM are shown in Figure 8, comparing the mixed flow and plug flow numerical models. Both models show good agreement in the total amount of heat discharged (area under the presented curves) by the systems with and without PCM. The inclusion of PVC tubes containing PCM inside the domestic hot water cylinder reduces the volume of water. However, it increases the total amount of heat discharged from 49 kJ to 52.5 kJ.

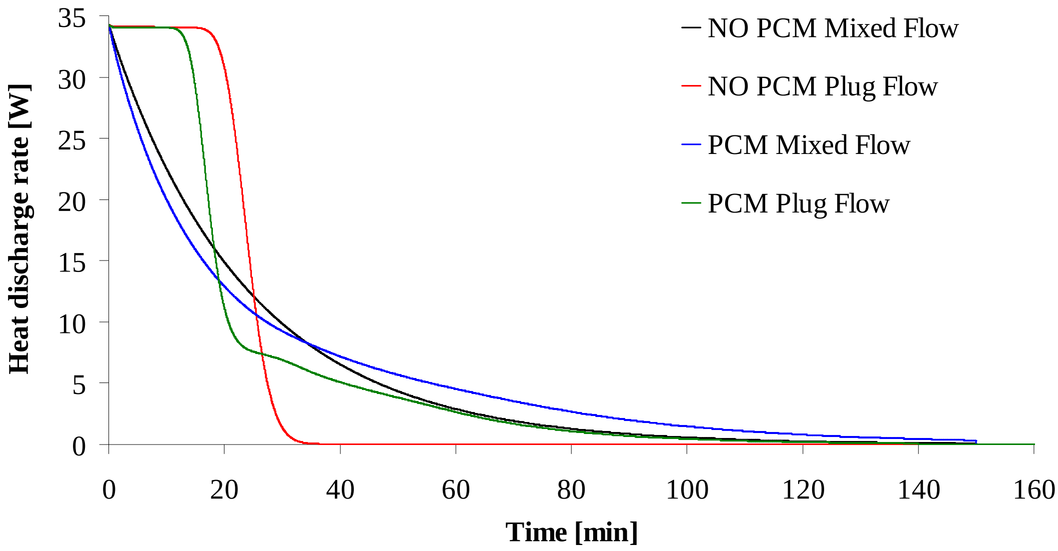

Figure 8. One-dimensional and two-dimensional model comparison

In addition, since fixed mass flow rate was set in those tests, the rate of energy discharged decreases according to the discharged water temperature. The temperature of the discharged water in the fully mixed flow models decreases slowly but constantly while in the plug mixed flow models it is maintained during a certain period (12 and 17 minutes in the system with PCM and in the system without, respectively). After this period the temperature of discharge drops very fast in the system without PCM, while in the system with PCM the heat received by water from PCM keep the water temperature high for longer periods.

4.2 Electrical heat charge during night

The water temperature evolution through time during electrical heat charge for the nine different cases considered is shown in Figure 9. The case without PCM (case 0) shows slower increase in water temperature than all the cases with PCM before PCM starts to melt, because of the higher heat capacity of the water compared to PCM.

During the melting process of the PCM the thermal response of the system changes drastically among the different cases. Using thin tubes provides faster melting and hence more latent heat effect, decreasing the slop of the curve. On the other hand if thicker tubes are used, when the temperature of the water reaches the set point, the PCM may have not been fully melted. Following that, the water temperature dropped very rapidly due to the large amount of heat absorbed by the PCM during its partial melting. Once the water temperature reaches the lower set point, the controller switched on the heating again. The time needed to melt all the PCM inside the PVC tubes of each of the analyzed cases is shown in Table 3. Using large diameter tubes provides limited heat transfer and hence increases the time needed to melt the PCM (7 hours for the case 8).

The electric energy consumed and the theoretical thermal energy stored by each system are also presented in Table 3. The thermal energy stored by the system from its initial temperature of 23ºC up to the final temperature of 80ºC takes into account the energy stored by the PCM, the water, the PVC tubes, the steel tank wall, and the insulation. As expected, the addition of PCM increases the electrical energy consumed during the night and hence the thermal energy available for later daily uses.

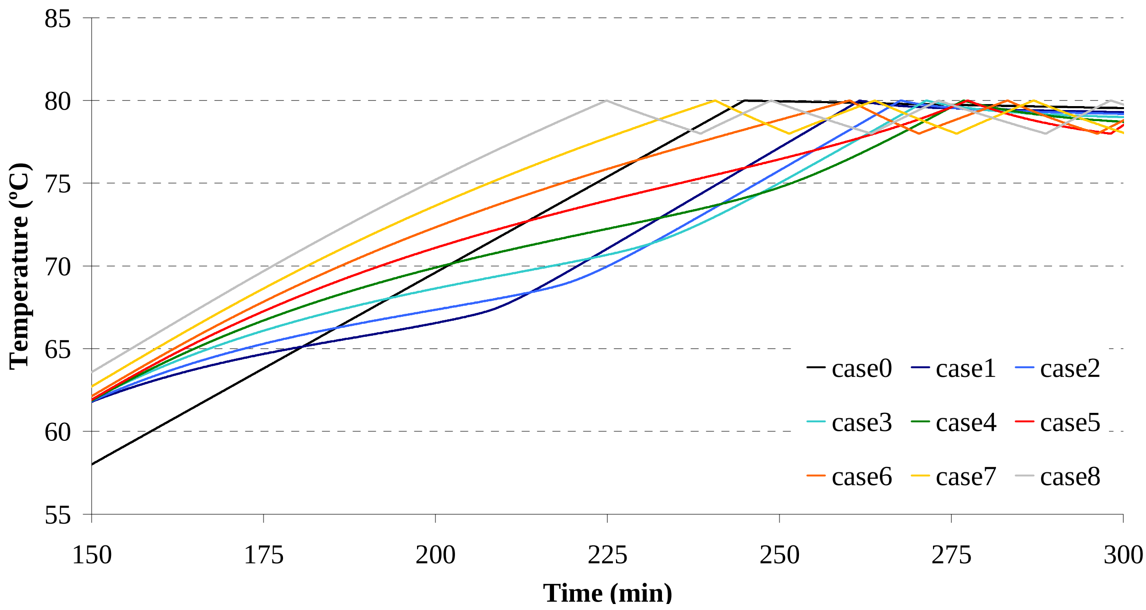

Figure 9. Water temperature comparison during electrical heat charge (23ºC to 80ºC)

Table 3. Total energy consumed and thermal energy stored during electrical heating.

	Time to melt the PCM (min)	Mass of PCM (kg)	Electrical energy consumed (kWh)	Thermal Energy Stored (kWh)
Case 0	-	0	13.97	11.92
Case 1	207.70	41.57	14.83	13.10
Case 2	218.43	45.17	15.41	13.44
Case 3	230.20	47.68	15.55	13.67
Case 4	247.53	51.54	15.78	14.04
Case 5	**266.67**	**54.66**	**16.14**	**14.33**
Case 6	292.93	56.44	16.37	14.53
Case 7	341.03	59.69	16.76	14.80
Case 8	428.30	60.18	16.99	14.90

Table 3 shows that the stored energy is significantly increased through the use of PCM (case 0 compared to other cases). The increment in the energy stored among the different cases (1 to 8) is due to the higher mass of PCM used.

4.3 Scenario 1

The water temperature evolution through time at the top of the tank during the hot water demand described in Scenario 1, is shown in Figure 10 and Figure 11. The heat transfer area between the water and the PVC tubes is critical to describe the thermal response of the system. The only case including PCM that provides longer time of hot water availability during the first discharge than the case without PCM (case 0) is case 1.

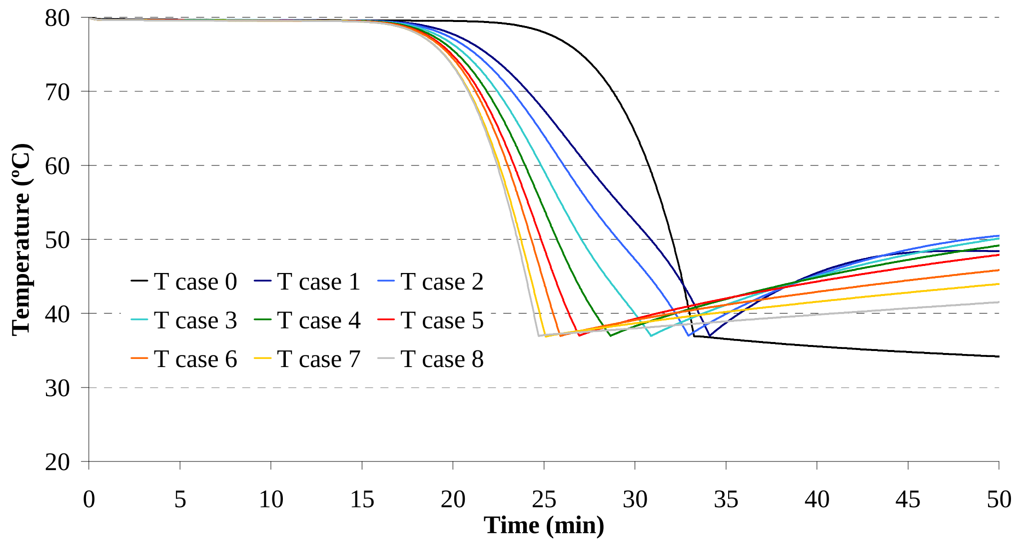

Figure 10. Temperature evolution through time of discharged water. 1st discharge.

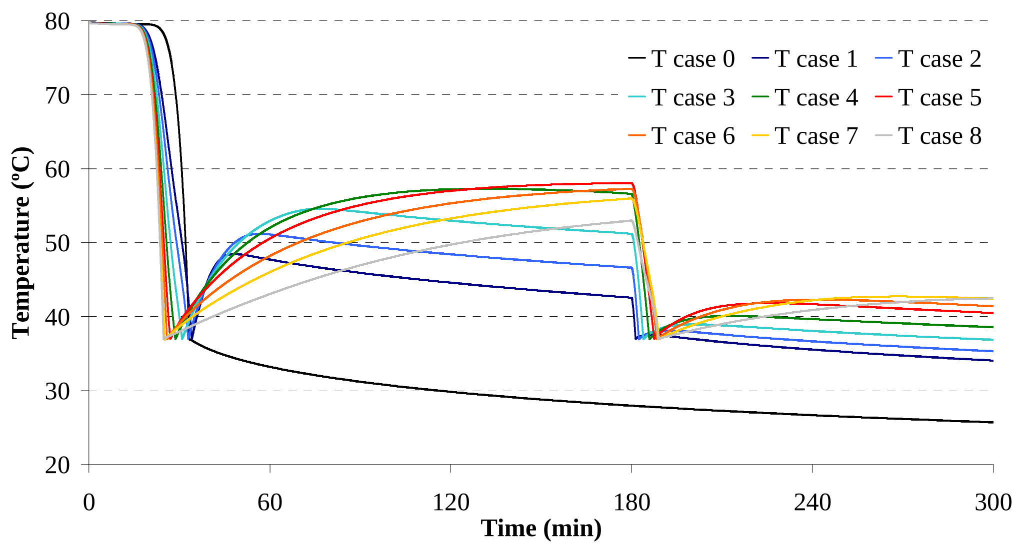

Figure 11. Temperature evolution through time of discharged water. (Scenario 1)

Even though case 0 has 180 L of hot water to discharge, and the case with 356 tubes containing PCM has only 123 L, the heat stored by the PCM is realised rapidly to the water, which provides longer period of hot water availability during the first discharge. Meanwhile for all the other cases with PCM, the period of the first discharge is reduced because of the reduction in the hot water volume and because the PCM releases its heat to the water slowly. It is important to mention here that increasing the first discharge period is not an objective to enhance in this study.

After this first discharge the case with no PCM has discharged all its stored thermal energy and the system does not provide hot water anymore for next discharges. On the other hand, when PCM is included, the water contained in the tanks with PCM is heated up by the PCM and can provide hot water for future demands. As it was expected, depending on the PCM distribution inside the tank, the water temperature will have different thermal responses. In the cases with large number of small diameter tubes (case 1, case 2 and case 3), the fast heat transfer between PCM and the water increases the water temperature much faster. The temperature at the top decreases during the period between discharges due to the heat losses to the environment and the mixing inside the tank (note that tap water at 14.5 ºC is introduced to the system from the bottom). That reduces significantly the capacity of providing hot water during the second discharge. On the other hand, the PCM contained in the systems with larger diameter tubes (case 7 and case 8) was still giving heat to the water when second discharge occurred. In addition it can be observed that in cases 4, 5 and 6 the water temperature achieves the phase change temperature (around 58ºC) close to the second demanded discharge, optimizing the use of stored heat by the PCM.

The temperature evolution of the top node of PCM at the centre of the PVC tube (r=0) for all the analyzed cases are presented in Figure 12. As it was previously said, the PCM contained in cases 1, 2 and 3 has lost its latent heat before the second discharge, limiting the capacity of providing hot water during this second period of demand. Moreover, during this period, PCM is completely solidified in cases 4 and 5, while it is not in cases 6, 7 and 8. However, because of the mixing of water, the PCM that remains melted after both discharges is fully solidified providing no benefits in the energetic efficiency of those systems.

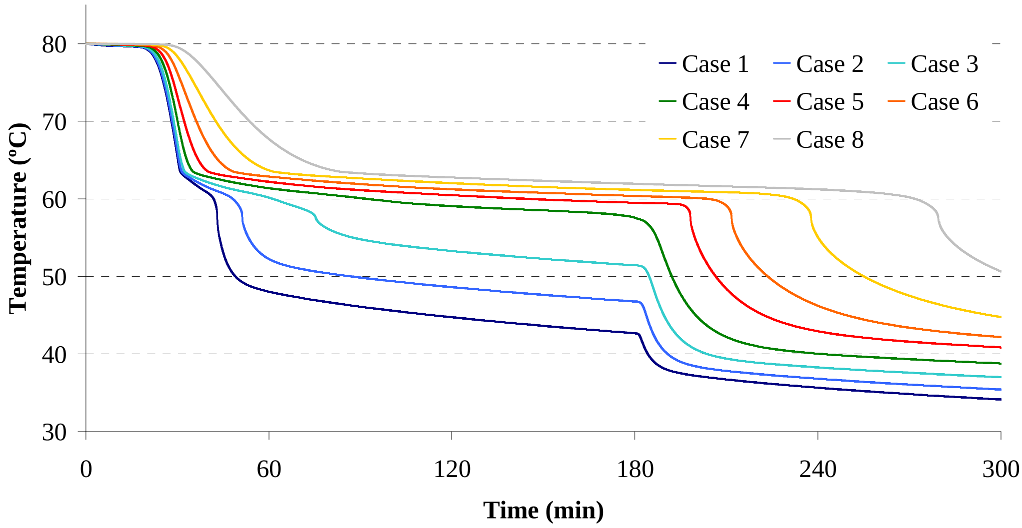

Figure 12. PCM temperature evolution through time (Scenario 1 - 180 min between discharges)

4.4 Scenario 2

Thermal response of the systems during Scenario 2 of hot water demand is presented in Figure 13. The temperature evolution during the first discharge is the same as the one described in Scenario 1. Since the period between discharges has increased from 180 to 360 minutes, the cases with small diameter tubes and hence with fast heat transfer are affected heavily by the mixing of water, reducing their capacity of providing hot water for the demanded second discharge. However, the discharge capacity during the second demand of hot water has increased in the cases of larger diameter tubes because the time between the discharges was sufficient to recover the heat stored by the PCM.

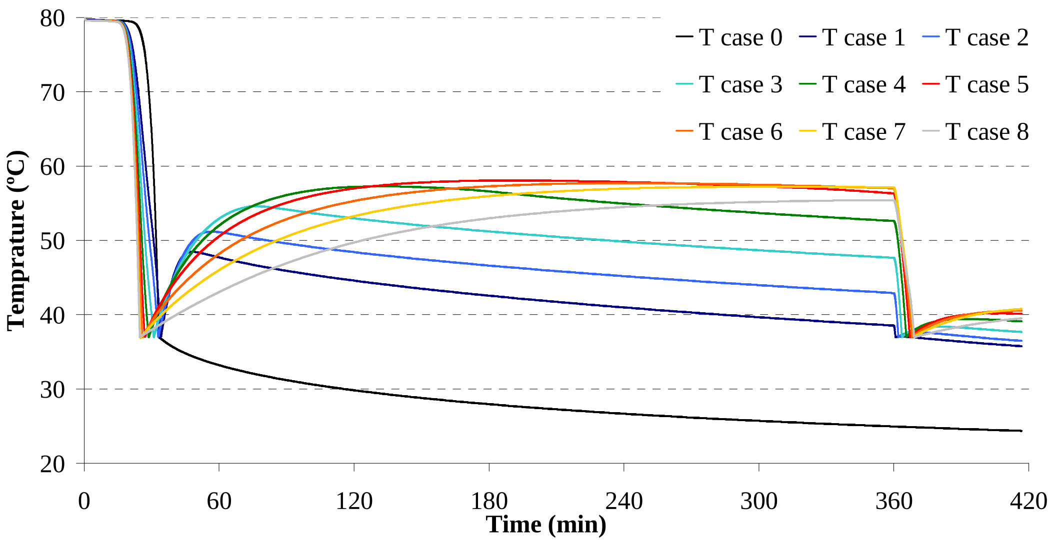

Figure 13. Temperature evolution through time of discharged water (Scenario 2 - 360 min between discharges).

The discharge capacity of all the studied cases during Scenario 1 and 2 are compared in Figure 14. As it was previously discussed, the PCM in the small tubes gives its energy fast to the water increasing the discharge capacity during the first hot water demand, but having a reduced capacity of discharging hot water in later uses. On the other hand systems with larger diameter tubes provide slow heat transfering to the water and hence more heat available during the second demand.

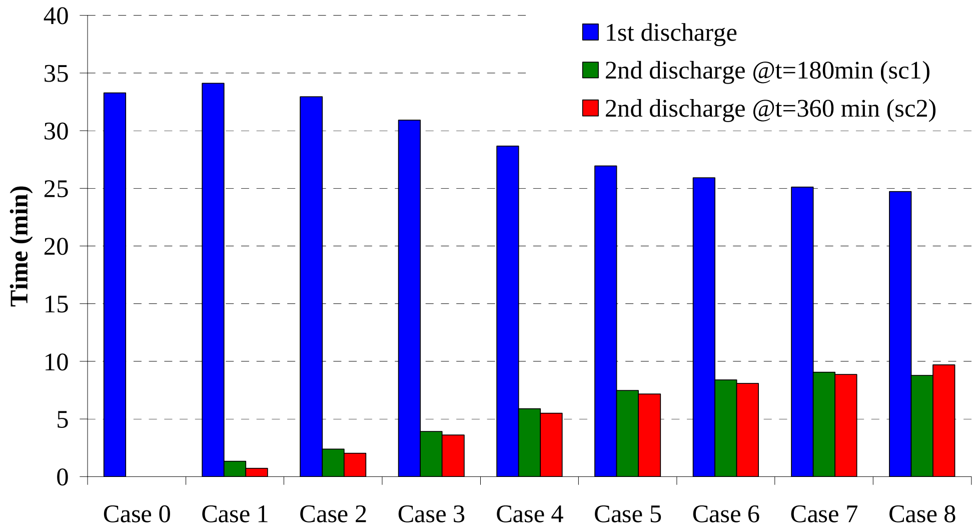

Figure 14. Parametric comparison of discharge capacity (Scenarios 1 and 2).

4.5 Scenario 3

Temperature evolution through time during intermittent demands of hot water are presented in Figure 15. The system with no PCM (case 0) is only able to fully cover the demand during the first two discharges (at t=0 and at t=60 min) and to cover partially the demand during the third discharge (8 minutes discharged from 10 demanded). Hence, this system covers 40% of the hot water discharged demand (28 minutes from the 70 minutes requested). On the other hand, the systems including PCM, after fully covering the first three discharges can still provide hot water during the following demands, and increase the demand coverage to around 55%. The discharge capacity of the different systems is compared in Figure 16. It can be observed that except cases 7 and 8, all the other systems cover the 50% of the fourth water demand. The capacity of covering the demand after the fourth discharge decreases dramatically in all the cases, being less than 10% in the systems with large number of small diameter tubes. The systems that include large diameter tubes (case 6, 7 and 8) can provide short discharges during fifth and sixth demand.

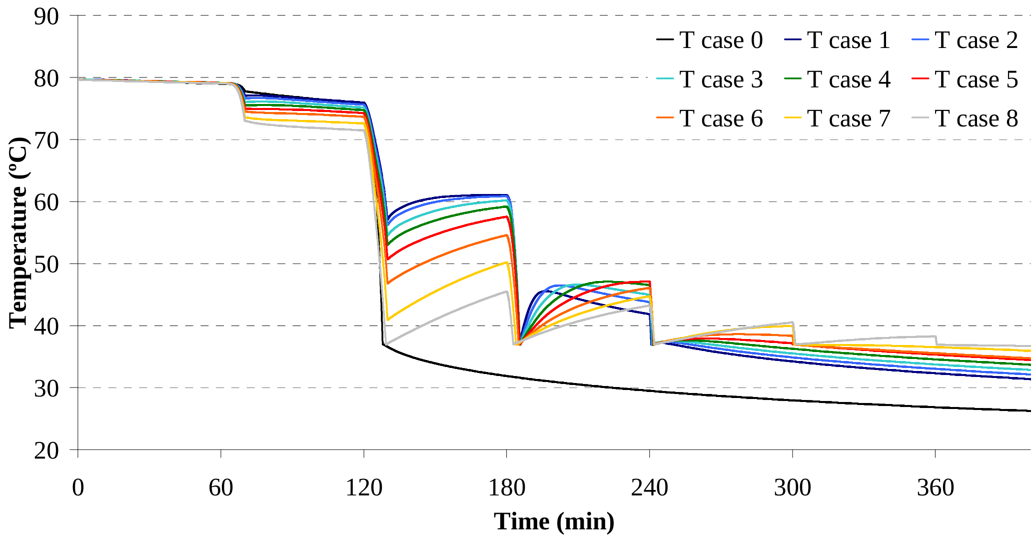

Figure 15. Temperature evolution through time of discharged water (Scenario 3 - Intermittent discharges).

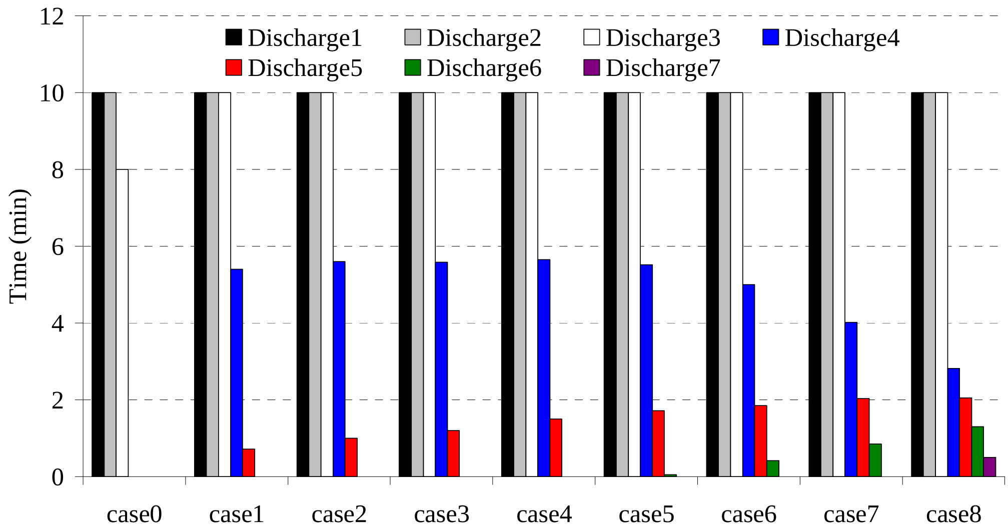

Figure 16. Parametric comparison of discharge capacity (Scenario 3).

5 Concluding remarks

The present work analyzes the improvement in thermal performance due to the inclusion of encapsulated phase change materials inside a domestic hot water cylinder. A numerical model using finite difference method was validated experimentally and then used to optimize the PCM distribution inside the water cylinder under different hot water demand scenarios.

The off-peak electricity available during night was sufficient to fully melt the PCM in all the evaluated cases. Even though the amount of water inside the tank is reduced because of the tubes containing the PCM, the systems with PCM have higher hot water discharge capacity, and their demand coverage increase from 40% to 55% (scenario 3).

The numerical parametric analysis concludes that the PCM distribution inside the tank must be defined depending on the timing and quantity of hot water demand. The systems with large number of small tubes can provide hot water longer time during the first discharge but limited time in the other discharges. In these systems part of the heat stored by the PCM is realized to the water during this first discharge because of the high area of heat transfer between the PVC tubes and the water. On the other hand, systems with less tubes of larger diameter store the heat in the PCM for posterior demands.

Nomenclature

C_p	Specific heat	$J\ kg^{-1}\ K^{-1}$
Gr	Grashof number	
h	Convective heat transfer coefficient	$W\ m^{-2}\ K^{-1}$
H	Total volumetric enthalpy	$J\ m^{-3}$
k	Thermal conductivity	$W\ m^{-1}\ K^{-1}$
$\dot{m}$	Mass flow rate	$kg\ s^{-1}$
Nu	Nusselt number	
Pr	Prandtl number	
$\dot{q}$	Power of heat generation	W
r	Radius	m
Re	Reynolds number	
t	Time	s
T	Temperature	ºC or K
v	Velocity	$m\ s^{-1}$

Greek symbols

λ	Latent heat	$kJ\ kg^{-1}$
ρ	Density	$kg\ m^{-3}$

Subscripts

0	Initial
env	environment
L	Liquid
S	Solid
w	Water
y	Vertical direction
W, E, P, N, S	West, east, centre, north and south nodes

Superscripts

n	Value at the present instant of time
n+1	Value at the following instant of time

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Appendix 1. Numerical code for the electrical heating (case 5).

```
#include<stdio.h>
#include<math.h>
#include<stdlib.h>
#define pi 3.14159
int main()
{
FILE *trans;
trans = fopen ("case5_el.txt", "w" );
/**---------------------------------------------------------------------------**/
/*Variable definitions*/
static double T[35][50001];
static double Ta[35][50001];
static double alpha1[50001];
static double alpha2[50001];
static double alpha3[50001];
static double alpha4[50001];
static double alpha5[50001];
float mfr=0, T_initial=0;
static double Cp_PCM[1000];
static double tc_PCM[100];
static double density_PCM[100];
static double iter[50001];
static double Q_elec[50001];
float tc_PVC=0, r_PVC=0, thick_PVC=0, Cp_PVC=0, density_PVC=0, n_tubes=0, T_air=0, est=0;
double Gr=0, Pr=0, beta=0, g=9.81, density_water=0, Cp_water=0, visco=0, Tfilm=0, tc_water=0, Nu=0, F=0, G=0, Vol_w=0, Vol_tank=0,
Inc_tita=0;
```

```
float density_PCM_i=0, tc_PCM_i=0, density_air=0, Cp_air, tc_air=0, visc_air=0, density_steel=0, tc_steel=0, Cp_steel=0, density_PU=0,
tc_PU=0, Cp_PU=0, thick_steel=0, thick_PU=0, thick_PCM, diameter_tank=0;
float rw[35], re[35], ri[35], time=0;
float Sw=0, Se=0, Sz=0, Vol=0, Vol_PVC=0, Sconv1=0, Sz_PVC=0, Vol_PCM=0, Sconv2=0, Sconv3=0, Sconv4=0, Sconv5=0, length=0,
diameter_tube=0, vol_tube, diameter_i_tank=0, diameter_o_tank=0;
float max_error=0, Inc_PCM=0, Inc_PVC=0, Inc_steel=0, Inc_PU=0,Inc_t=1, Inc_z=0, Total_time=0, q=0, o=0, Sz_PCM=0, Sz_steel=0,
Vol_steel=0, Sz_PU=0, Vol_PU=0, vol_steel_inside=0;
int i=0, t=0, j=0, y=0, k=0, max_iter=10000, N=0, L=0, M=0, R=0, Q=0, w=0, p=0;
static double errort=0, error=0, a=0, b=0, c=0, d=0, e=0, h=0, Cp_i=0, rel=0, heat_consumed=0;
/**float alpha=0;**/
/**---------------------------------------------------------------------------------**/
/*Number of nodes*/
N=10; /**PCM**/
M=5; /**PVC**/
R=3; /**steel**/
Q=8; /**PU**/
w=N+M+R+Q+2;
/*Physical properties and geometrical data input*/
for(i=0;i<=56;i++)
{
density_PCM[i]=1400;
tc_PCM[i]=0.54;
}
density_PCM[57]=1372.5;
density_PCM[58]=1345;
density_PCM[59]=1317.5;
tc_PCM[57]=0.6775;
tc_PCM[58]=0.815;
tc_PCM[59]=0.9525;
```

```
for(i=60;i<=100;i++)
{
density_PCM[i]=1290;
tc_PCM[i]=1.09;
}
tc_PVC=0.12;
Cp_PVC=880;
density_PVC=1100;
density_steel=7901;
tc_steel=15.17;
Cp_steel=481;
density_PU=35;
tc_PU=0.028;
Cp_PU=1000;
n_tubes=57;
diameter_tank=0.474;
diameter_i_tank=diameter_tank;
diameter_o_tank=diameter_tank+2*thick_steel+2*thick_PU;
diameter_tube=0.04;
length=1.02;
vol_tube=pi*diameter_tube*diameter_tube*0.25*length*0.75;
vol_steel_inside=0.0036;
Vol_tank=0.180-n_tubes*vol_tube-vol_steel_inside;
Total_time=43200;

/**Parameters input*/
thick_PVC=0.00295;
thick_steel=0.003;
thick_PU=0.017;
thick_PCM=0.5*(diameter_tube-2*thick_PVC);
```

```
Inc_PCM=thick_PCM/N;
Inc_PVC=thick_PVC/M;
Inc_steel=thick_steel/R;
Inc_PU=thick_PU/Q;
Inc_z=0.75;
max_error=0.00001;
max_iter=1000000;
rel=1;
T_initial=23;
T_air=21;
Inc_t=2;
p=0;

/**Calcul radis*/
ri[0]=0;
re[0]=Inc_PCM/2;
ri[1]=Inc_PCM;
rw[1]=Inc_PCM/2;
re[1]=3*Inc_PCM/2;
for(i=2;i<N;i++)
{
ri[i]=ri[i-1]+Inc_PCM;
re[i]=ri[i]+Inc_PCM/2;
rw[i]=ri[i]-Inc_PCM/2;
}
ri[N]=thick_PCM;
rw[N]=ri[N]-Inc_PCM/2;
re[N]=ri[N]+Inc_PVC/2;
```

```
for(i=N+1;i<N+M;i++)
{
ri[i]=ri[i-1]+Inc_PVC;
re[i]=ri[i]+Inc_PVC/2;
rw[i]=ri[i]-Inc_PVC/2;
}
ri[N+M]=thick_PCM+thick_PVC;
rw[N+M]=ri[N+M]-Inc_PVC/2;
ri[N+M+2]=diameter_tank/2;
re[N+M+2]=ri[N+M+2]+Inc_steel/2;
for(i=N+M+3;i<(N+M+R+2);i++)
{
ri[i]=ri[i-1]+Inc_steel;
re[i]=ri[i]+Inc_steel/2;
rw[i]=ri[i]-Inc_steel/2;
}
ri[N+M+R+2]=diameter_tank/2+thick_steel;
rw[N+M+R+2]=ri[N+M+R+2]-Inc_steel/2;
re[N+M+R+2]=ri[N+M+R+2]+Inc_PU/2;
for(i=N+M+R+3;i<w;i++)
{
ri[i]=ri[i-1]+Inc_PU;
re[i]=ri[i]+Inc_PU/2;
rw[i]=ri[i]-Inc_PU/2;
}
ri[w]=diameter_tank/2+thick_steel+thick_PU;
rw[w]=ri[N+M+R+Q+1]-Inc_PU/2;
```

```
/**Cp vs T input**/
for(i=0;i<=575;i++)
{
Cp_PCM[i]=2880;
}

Cp_PCM[576]=5092;
Cp_PCM[577]=7304;
Cp_PCM[578]=9516;
Cp_PCM[579]=11728;
Cp_PCM[580]=13940;
Cp_PCM[581]=16152;
Cp_PCM[582]=18364;
Cp_PCM[583]=20576;
Cp_PCM[584]=22788;
Cp_PCM[585]=25000;
Cp_PCM[586]=26500;
Cp_PCM[587]=28000;
Cp_PCM[588]=29500;
Cp_PCM[589]=31000;
Cp_PCM[590]=32500;
Cp_PCM[591]=34000;
Cp_PCM[592]=35500;
Cp_PCM[593]=37000;
Cp_PCM[594]=38500;
Cp_PCM[595]=40000;
Cp_PCM[596]=43000;
Cp_PCM[597]=46000;
Cp_PCM[598]=49000;
Cp_PCM[599]=52000;
```

```
Cp_PCM[600]=55000;
Cp_PCM[601]=58000;
Cp_PCM[602]=61000;
Cp_PCM[603]=64000;
Cp_PCM[604]=67000;
Cp_PCM[605]=70000;
Cp_PCM[606]=67000;
Cp_PCM[607]=64000;
Cp_PCM[608]=61000;
Cp_PCM[609]=58000;
Cp_PCM[610]=55000;
Cp_PCM[611]=52000;
Cp_PCM[612]=49000;
Cp_PCM[613]=46000;
Cp_PCM[614]=43000;
Cp_PCM[615]=40000;
Cp_PCM[616]=38500;
Cp_PCM[617]=37000;
Cp_PCM[618]=35500;
Cp_PCM[619]=34000;
Cp_PCM[620]=32500;
Cp_PCM[621]=31000;
Cp_PCM[622]=29500;
Cp_PCM[623]=28000;
Cp_PCM[624]=26500;
Cp_PCM[625]=25000;
Cp_PCM[626]=22919;
Cp_PCM[627]=20838;
Cp_PCM[628]=18757;
Cp_PCM[629]=16676;
```

```
Cp_PCM[630]=14595;
Cp_PCM[631]=12514;
Cp_PCM[632]=10433;
Cp_PCM[633]=8352;
Cp_PCM[634]=6271;
for(i=635;i<=1000;i++)
{
Cp_PCM[i]=4190;
}
/**---------------------------------------------------------------------------**/
/**Electric power input*/

for(t=0;t<Total_time;t++)
{
Q_elec[t]=3000;
}
/**---------------------------------------------------------------------------**/
/*Array initialization*/
for(i=0;i<=w;i++)
{
for(t=0;t<=Total_time;t++)
{
T[i][t]=0;
Ta[i][t]=0;
alpha1[t]=0;
alpha2[t]=0;
alpha3[t]=0;
iter[t]=0;
}
}
```

```
/**---------------------------------------------------------------------------**/
/*Initial map temperatures*/
t=0;
for(i=0;i<=w;i++)
{
T[i][t]=T_initial;
Ta[i][t]=T_initial;
}

/**---------------------------------------------------------------------------**/
while(t<Total_time)
{
   /*New instant*/
   t=t+1;
    if(T[N+M+1][t-1]>=80)
   {
   p=1;
   Q_elec[t]=0;
   }
   if((T[N+M+1][t-1]>78)&&(p==1))
   Q_elec[t]=0;

   if((T[N+M+1][t-1]<=78))
   p=0;
/**----------------------**/
         for (i=0;i<=w;i++)
   {
   Ta[i][t]=T[i][t-1];
   }
   /**-----------------------------------------------------------------------**/
```

```
for(y=0;y<max_iter;y++)
{
   errort=0;
         for(i=0;i<=w;i++)
         {
         if(i==0)
         {
         Se=2*pi*re[i]*(Inc_z);
         Sz=pi*re[i]*re[i];
         Vol=Sz*(Inc_z);
         k=Ta[i][t];
         h=Ta[i][t]-k;
         tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
         density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;
         k=Ta[i][t]*10;
         h=Ta[i][t]*10-k;
         Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;
         d=tc_PCM_i*Se/Inc_PCM;
         e=density_PCM_i*Cp_i*Vol/Inc_t;
         a=d+e;
         T[i][t]=(d*Ta[i+1][t]+e*T[i][t-1])/a;
         }
         if((i>0)&&(i<N))
         {
         Se=2*pi*re[i]*(Inc_z);
         Sw=2*pi*rw[i]*(Inc_z);
         Sz=pi*(re[i]*re[i]-rw[i]*rw[i]);
         Vol=Sz*(Inc_z);
         k=Ta[i][t];
         h=Ta[i][t]-k;
```

```
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;
k=Ta[i][t]*10;
h=Ta[i][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;
b=tc_PCM_i*Sw/Inc_PCM;
d=tc_PCM_i*Se/Inc_PCM;
e=density_PCM_i*Cp_i*Vol/Inc_t;
a=b+d+e;
T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
}
if(i==N)
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PCM=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PVC=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_PCM=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PVC=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;
k=Ta[i][t];
h=Ta[i][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;
k=Ta[i][t]*10;
h=Ta[i][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;
b=tc_PCM_i*Sw/Inc_PCM;
d=tc_PVC*Se/Inc_PVC;
e=(density_PCM_i*Cp_i*Vol_PCM/Inc_t+density_PVC*Cp_PVC*Vol_PVC/Inc_t);
a=b+d+e;
```

```
T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
}
/**-----------------**/
if((i>N)&&(i<N+M))
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PVC=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PVC=Sz_PVC*Inc_z;

b=tc_PVC*Sw/Inc_PVC;
d=tc_PVC*Se/Inc_PVC;
e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
a=b+d+e;
T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
}
if(i==N+M)
{
Sconv1=2*pi*ri[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PVC=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PVC=Sz_PVC*Inc_z;

Tfilm=(Ta[i+1][t]+Ta[i][t])/2;

beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
```

```
    Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
    tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
    Inc_tita=fabs(Ta[i+1][t]-Ta[i][t]);
    q=g*beta*pow(density_water,2)*(Inc_tita);
    o=pow(Inc_z,3)/pow(visco,2);
    Gr=o*q;
    F=Gr*Pr;
    G=Pr/(1+1.05*Pr);
    /*Nu=0.686*pow(F,0.25)*pow(G,0.25);*/
    /*Nu=0.686*pow(F,0.25)*pow(G,0.25)+0.52*Inc_z/diameter_tube;*/
    Nu=0.59*pow(F,0.25);
    alpha1[t]=Nu*tc_water/(Inc_z);
    b=tc_PVC*Sw/Inc_PVC;
    d=alpha1[t]*Sconv1;
    e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
    a=b+d+e;
    T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
    }
    if(i==N+M+1)
    {
    Tfilm=(Ta[i][t]+Ta[i+1][t])/2;
    beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
    density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
    visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
    Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
    tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
    Inc_tita=fabs(Ta[i+1][t]-Ta[i][t]);
```

```
q=g*beta*pow(density_water,2)*(Inc_tita);
o=pow(length,3)/pow(visco,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha2[t]=Nu*tc_water/(Inc_z);
Cp_water=4171.33+0.301902*Ta[i][t]-0.0068101*Ta[i][t]*Ta[i][t]+0.0000664071*Ta[i][t]*Ta[i][t]*Ta[i][t];
Sconv1=n_tubes*2*pi*(ri[i-1])*(Inc_z);
Sconv2=2*pi*(ri[i+1])*length;
Vol_w=Vol_tank;
b=alpha1[t]*Sconv1;
d=alpha2[t]*Sconv2;
e=density_water*Cp_water*Vol_w/Inc_t+density_steel*Cp_steel*vol_steel_inside/Inc_t;
a=b+d+e;

T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1]+Q_elec[t])/a;
}

if(i==N+M+2)
{
Sconv2=2*pi*ri[i]*length;
Se=2*pi*re[i]*length;
Sz_steel=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=Sz_steel*length;

d=tc_steel*Se/Inc_steel;
b=alpha2[t]*Sconv2;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
a=b+d+e;
```

```
T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
}

if((i>N+M+2)&&(i<N+M+R+2))
{
Se=2*pi*re[i]*length;
Sw=2*pi*rw[i]*length;
Sz_steel=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_steel=Sz_steel*length;

b=tc_steel*Sw/Inc_steel;
d=tc_steel*Se/Inc_steel;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
a=b+d+e;
T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
}

if(i==N+M+R+2)
{
Se=2*pi*re[i]*length;
Sw=2*pi*rw[i]*length;
Sz_steel=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PU=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=(ri[i]*ri[i]-rw[i]*rw[i])*pi*length;
Vol_PU=(re[i]*re[i]-ri[i]*ri[i])*pi*length;

b=tc_steel*Sw/Inc_steel;
d=tc_PU*Se/Inc_PU;
e=(density_steel*Cp_steel*Vol_steel/Inc_t+density_PU*Cp_PU*Vol_PU/Inc_t);
a=b+d+e;
```

```
T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
}

if((i>N+M+R+2)&&(i<w))
{
Se=2*pi*re[i]*length;
Sw=2*pi*rw[i]*length;
Sz_PU=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*length;

b=tc_PU*Sw/Inc_PU;
d=tc_PU*Se/Inc_PU;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e;
T[i][t]=(b*Ta[i-1][t]+d*Ta[i+1][t]+e*T[i][t-1])/a;
}


if(i==w)
{

Sconv3=2*pi*ri[i]*length;
Sconv4=pi*ri[i]*ri[i];
Sconv5=pi*ri[i]*ri[i];
Sw=2*pi*rw[i]*length;
Sz_PU=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*length;

Tfilm=273.15+((T_air+Ta[i][t])/2); /*Temperatura de l'aire amb graus kelvin*/
```

```
beta=0.0169811-0.0000855186*Tfilm+0.000000130714*Tfilm*Tfilm;
density_air=8.2131-0.0649*Tfilm+0.0002*Tfilm*Tfilm-0.0000002*Tfilm*Tfilm*Tfilm;
visc_air=-0.0000004+0.00000008*Tfilm-0.00000000005*Tfilm*Tfilm;
Pr=0.8073-0.0004*Tfilm+0.0000002*Tfilm*Tfilm;
tc_air=-0.0003+0.0001*Tfilm-0.00000004*Tfilm*Tfilm;
Inc_tita=fabs(T_air-Ta[i][t]);
q=g*beta*pow(density_air,2)*(Inc_tita);
o=pow(length,3)/pow(visc_air,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha3[t]=Nu*tc_air/length;

q=g*beta*pow(density_air,2)*(Inc_tita);
o=pow(diameter_tank,3)/pow(visc_air,2);
Gr=o*q;
F=Gr*Pr;
Nu=0.54*pow(F,0.25);
alpha4[t]=Nu*tc_air/diameter_tank;

Nu=0.27*pow(F,0.25);
alpha5[t]=Nu*tc_air/diameter_tank;


b=tc_PU*Sw/Inc_PU;
d=alpha3[t]*Sconv3+alpha4[t]*Sconv4+alpha5[t]*Sconv5;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e;
T[i][t]=(b*Ta[i-1][t]+d*T_air+e*T[i][t-1])/a;
```

```
            }


            }/**tanca el for i ++**/

/*Error calculation*/
   for (i=0;i<=w;i++)
   {
   error=fabs(T[i][t]-Ta[i][t]);
      if(error>errort)
      errort=error;
      else
      errort=errort;
   }

if(errort>max_error){
for (i=0;i<=w;i++)
   {

   Ta[i][t]=T[i][t]*rel+Ta[i][t]*(1-rel);
   }
}
if(errort<max_error)break;
}


heat_consumed=heat_consumed+Inc_t*Q_elec[t];


}
```

```
/**---------------------------------------------------------------------------**/

/**Print results**/

fprintf(trans, "time, T0_PCM, Tmid_PCM, Tout_PCM, TPVCext, Taigua, Tsteelint, Twallout, Heat_consumed %-2.5f,\n", heat_consumed);

t=0;
while(t<=Total_time/Inc_t)
{
time=Inc_t*t/60;
fprintf(trans, "%-2.5f,",time);
j=2;
fprintf(trans, "%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,",T[0][t],T[5][t], T[10][t], T[15][t], T[16][t],  T[17][t], T[28][t]);
fprintf(trans, "\n");
t=t+1;
}


printf("finished");
getch();

}
```

Appendix 2. Numerical code for the water discharge (Scenario 1 case 5).

```
#include<stdio.h>
#include<math.h>
#include<stdlib.h>

#define pi 3.14159
int main()
{
FILE *trans;
trans = fopen ("study1_case5.txt", "w" );

/**---------------------------------------------------------------------------------**/

/*Variable definitions*/
static double T[35][71][18001];
static double Ta[35][71][18001];
float alpha1, alpha2, alpha3, alpha4, alpha5;
float mfr=0, T_initial=0;
static float Cp_PCM[1001];
static float tc_PCM[101];
static float density_PCM[101];
float iter;
static float m_water[18001], thermal_energy[18001], Twater_inlet=0, h_innlet=0, h_outlet=0;
float tc_PVC=0, r_PVC=0, thick_PVC=0, Cp_PVC=0, density_PVC=0, n_tubes=0, T_air=0, est=0;
float Gr=0, Pr=0, beta=0, g=9.81, density_water=0, Cp_water=0, visco=0, Tfilm=0, tc_water=0, Nu=0, F=0, G=0, Vol_w=0, Vol_tank=0,
Inc_tita=0;
float density_PCM_i=0, tc_PCM_i=0, density_air=0, Cp_air, tc_air=0, visc_air=0, density_steel=0, tc_steel=0, Cp_steel=0, density_PU=0,
tc_PU=0, Cp_PU=0, thick_steel=0, thick_PU=0, thick_PCM, diameter_tank=0;
float rw[35], re[35], ri[35], opi=0, op1=0, op2=0, op3=0, op4=0, q=1, v=1;
```

```
float Sw=0, Se=0, Sz=0, Vol=0, Vol_PVC=0, Sconv1=0, Sz_PVC=0, Vol_PCM=0, Sconv2=0, Sconv3=0, Sconv4=0, Sconv5=0, length=0,
diameter_tube=0, vol_tube, diameter_i_tank=0, diameter_o_tank=0;
float max_error=0, Inc_PCM=0, Inc_PVC=0, Inc_steel=0, Inc_PU=0,Inc_t=1, Inc_z=0, Total_time=0, time=0, o=0, Sz_PCM=0, Sz_steel=0,
Vol_steel=0, Sz_PU=0, Vol_PU=0, vol_steel_inside=0;
int i=0, t=0, j=0, y=0, k=0, max_iter=10000, N=0, L=0, M=0, R=0, Q=0, w=0, p=0, t1=0, t2=0, t3=0, LPCM=0;
static double errort=0, error=0, a=0, b=0, c=0, d=0, e=0, f=0, h=0, Cp_i=0, rel=0, Tmean1=0, Tmean2=0, T_confort=0, Q_vol=0, time1=0,
time2=0, time3=0, time_on=0;
/**float alpha=0;**/
/**--------------------------------------------------------------------------**/

/*Number of nodes*/
N=10; /**PCM**/
M=5; /**PVC**/
R=3; /**steel**/
Q=8; /**PU**/
w=N+M+R+Q+2;

L=70;/**heigth**/
LPCM=L*0.25;

max_error=0.00001;
max_iter=1000000;
rel=1;
T_initial=80;
T_air=21;
Inc_t=1;
/*Physical properties and geometrical data input*/
for(i=0;i<=56;i++)
{
density_PCM[i]=1400;
```

```
tc_PCM[i]=0.54;
}

density_PCM[57]=1372.5;
density_PCM[58]=1345;
density_PCM[59]=1317.5;
tc_PCM[57]=0.6775;
tc_PCM[58]=0.815;
tc_PCM[59]=0.9525;

for(i=60;i<=100;i++)
{
density_PCM[i]=1290;
tc_PCM[i]=1.09;
}

tc_PVC=0.12;
Cp_PVC=880;
density_PVC=1100;

density_steel=7901;
tc_steel=15.17;
Cp_steel=481;

density_PU=35;
tc_PU=0.028;
Cp_PU=1000;

density_water=1005;
```

```
T_confort=37;
Q_vol=12;
n_tubes=57;
diameter_tank=0.474;
diameter_i_tank=diameter_tank;
diameter_o_tank=diameter_tank+2*thick_steel+2*thick_PU;
diameter_tube=0.04;
length=1.02;
vol_tube=pi*diameter_tube*diameter_tube*0.25*length*0.75;
vol_steel_inside=0.0036;
Vol_tank=0.180-n_tubes*vol_tube-vol_steel_inside;
Total_time=18000;
time1=40*60/Inc_t;
time2=(180*60)/Inc_t;
time3=200*60/Inc_t;
t1=time1;
t2=time2;
t3=time3;
q=1;

/**Parameters input*/
thick_PVC=0.00295;
thick_steel=0.003;
thick_PU=0.017;
thick_PCM=0.5*(diameter_tube-2*thick_PVC);

Inc_PCM=thick_PCM/N;
Inc_PVC=thick_PVC/M;
Inc_steel=thick_steel/R;
Inc_PU=thick_PU/Q;
```

```
Inc_z=length/L;



p=0;

/**Calcul radis*/
ri[0]=0;
re[0]=Inc_PCM/2;
ri[1]=Inc_PCM;
rw[1]=Inc_PCM/2;
re[1]=3*Inc_PCM/2;

for(i=2;i<N;i++)
{
ri[i]=ri[i-1]+Inc_PCM;
re[i]=ri[i]+Inc_PCM/2;
rw[i]=ri[i]-Inc_PCM/2;
}

ri[N]=thick_PCM;
rw[N]=ri[N]-Inc_PCM/2;
re[N]=ri[N]+Inc_PVC/2;

for(i=N+1;i<N+M;i++)
{
ri[i]=ri[i-1]+Inc_PVC;
re[i]=ri[i]+Inc_PVC/2;
rw[i]=ri[i]-Inc_PVC/2;
}
```

```
ri[N+M]=thick_PCM+thick_PVC;
rw[N+M]=ri[N+M]-Inc_PVC/2;

ri[N+M+2]=diameter_tank/2;
re[N+M+2]=ri[N+M+2]+Inc_steel/2;

for(i=N+M+3;i<(N+M+R+2);i++)
{
ri[i]=ri[i-1]+Inc_steel;
re[i]=ri[i]+Inc_steel/2;
rw[i]=ri[i]-Inc_steel/2;
}

ri[N+M+R+2]=diameter_tank/2+thick_steel;
rw[N+M+R+2]=ri[N+M+R+2]-Inc_steel/2;
re[N+M+R+2]=ri[N+M+R+2]+Inc_PU/2;

for(i=N+M+R+3;i<w;i++)
{
ri[i]=ri[i-1]+Inc_PU;
re[i]=ri[i]+Inc_PU/2;
rw[i]=ri[i]-Inc_PU/2;
}

ri[w]=diameter_tank/2+thick_steel+thick_PU;
rw[w]=ri[N+M+R+Q+1]-Inc_PU/2;
```

```
/**Cp vs T input**/

for(i=0;i<=575;i++)
{
Cp_PCM[i]=2880;
}

Cp_PCM[576]=5092;
Cp_PCM[577]=7304;
Cp_PCM[578]=9516;
Cp_PCM[579]=11728;
Cp_PCM[580]=13940;
Cp_PCM[581]=16152;
Cp_PCM[582]=18364;
Cp_PCM[583]=20576;
Cp_PCM[584]=22788;
Cp_PCM[585]=25000;
Cp_PCM[586]=26500;
Cp_PCM[587]=28000;
Cp_PCM[588]=29500;
Cp_PCM[589]=31000;
Cp_PCM[590]=32500;
Cp_PCM[591]=34000;
Cp_PCM[592]=35500;
Cp_PCM[593]=37000;
Cp_PCM[594]=38500;
Cp_PCM[595]=40000;
Cp_PCM[596]=43000;
Cp_PCM[597]=46000;
Cp_PCM[598]=49000;
```

```
Cp_PCM[599]=52000;
Cp_PCM[600]=55000;
Cp_PCM[601]=58000;
Cp_PCM[602]=61000;
Cp_PCM[603]=64000;
Cp_PCM[604]=67000;
Cp_PCM[605]=70000;
Cp_PCM[606]=67000;
Cp_PCM[607]=64000;
Cp_PCM[608]=61000;
Cp_PCM[609]=58000;
Cp_PCM[610]=55000;
Cp_PCM[611]=52000;
Cp_PCM[612]=49000;
Cp_PCM[613]=46000;
Cp_PCM[614]=43000;
Cp_PCM[615]=40000;
Cp_PCM[616]=38500;
Cp_PCM[617]=37000;
Cp_PCM[618]=35500;
Cp_PCM[619]=34000;
Cp_PCM[620]=32500;
Cp_PCM[621]=31000;
Cp_PCM[622]=29500;
Cp_PCM[623]=28000;
Cp_PCM[624]=26500;
Cp_PCM[625]=25000;
Cp_PCM[626]=22919;
Cp_PCM[627]=20838;
Cp_PCM[628]=18757;
```

```
Cp_PCM[629]=16676;
Cp_PCM[630]=14595;
Cp_PCM[631]=12514;
Cp_PCM[632]=10433;
Cp_PCM[633]=8352;
Cp_PCM[634]=6271;
for(i=635;i<=1000;i++)
{
Cp_PCM[i]=4190;
}

/**---------------------------------------------------------------------------**/
/***/

Twater_inlet=14.5;

for(t=0;t<=Total_time;t++)
{
if(t<t1)
m_water[t]=0.125;

if((t>=t1)&&(t<t2))
m_water[t]=0;

if((t>=t2)&&(t<t3))
m_water[t]=0.125;

if((t>=t3)&&(t<Total_time))
m_water[t]=0;
```

```
}

/**---------------------------------------------------------------------------**/

/*Array initialization*/
for(j=0;i<L;j++)
{
for(i=0;i<=w;i++)
{
for(t=0;t<=Total_time;t++)
{
T[i][j][t]=0;
Ta[i][j][t]=0;
}
}
}
/**---------------------------------------------------------------------------**/

/*Initial map temperatures*/
for(j=0;j<L;j++)
{
t=0;
for(i=0;i<=w;i++)
{
if(i<N+M+1)
{
T[i][j][t]=T_initial;
Ta[i][j][t]=T_initial;
}
```

```
if(i==N+M+1)
{
T[i][j][t]=T_initial;
Ta[i][j][t]=T_initial;
}

if((i>=N+M+2)&&(i<=N+M+R+2))
{
op1=N;
op2=M;
op3=R;
opi=i;

T[i][j][t]=70-3*(opi-op1-op2-2)/op3;
Ta[i][j][t]=70-3*(opi-op1-op2-2)/op3;
}

if((i>N+M+R+2)&&(i<=N+M+R+Q+2))
{
op1=N;
op2=M;
op3=R;
op4=Q;
opi=i;

T[i][j][t]=67-34*(opi-op1-op2-op3-2)/op4;
Ta[i][j][t]=67-34*(opi-op1-op2-op3-2)/op4;
}
}
}
```

```
/**----------------------------------------------------------------------------**/
while(t<Total_time)
{
   /*New instant*/
   t=t+1;



/**----------------------**/

   for (j=0;j<L;j++)
   {
   for (i=0;i<=w;i++)
   {
   Ta[i][j][t]=T[i][j][t-1];
   }
   }


   if(m_water[t]==0)
   {
   a=1;
   }

   if((T[N+M+1][L-1][t-1]<T_confort)&&(v==1)&&(t<t2))
   {
   m_water[t]=0;
   v=0;
   }
```

```
if((v==0)&&(t<=t2))
{
m_water[t]=0;
}

if((v==0)&&(T[N+M+1][L-1][t-1]<T_confort)&&(t>t2))
{
m_water[t]=0;
v=1;
}

if((v==1)&&(t>t2))
{
m_water[t]=0;
}

if(m_water[t]>0)
{
m_water[t]=((Q_vol*density_water*0.0000166667*(4.18555*T_confort-4.18555*Twater_inlet))/(4.18555*T[N+M+1][L-1][t-1]-
4.18555*Twater_inlet));
}



/**----------------------------------------------------------------------**/
for(y=0;y<max_iter;y++)
{
   errort=0;
   for(j=0;j<L;j++)
```

```
{

if(j==0)
{

    for(i=0;i<=w;i++)
    {
    if(i==N+M+1)
    {
    Tfilm=(Ta[i][j][t]+Ta[i+1][j][t])/2;

    beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
    density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
    visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
    Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
    tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
    Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
    q=g*beta*pow(density_water,2)*(Inc_tita);
    o=pow(Inc_z*0.5,3)/pow(visco,2);
    Gr=o*q;
    F=Gr*Pr;
    G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
    Nu=0.8*pow(F,0.25)*G;
    alpha2=Nu*tc_water/(Inc_z*0.5);
    Cp_water=4171.33+0.301902*Ta[i][j][t]-0.0068101*Ta[i][j][t]*Ta[i][j][t]+0.0000664071*Ta[i][j][t]*Ta[i][j][t]*Ta[i][j][t];

    h_innlet=0.153035+4.18555*Twater_inlet;
    h_outlet=0.153035+4.18555*Ta[i][j][t];
```

```
Sconv2=2*pi*(ri[i+1])*Inc_z*0.5;
Vol_w=0.5*Vol_tank/L;
Sz=pi*(ri[i+1])*(ri[i+1]);

c=tc_water*Sz/Inc_z;
d=alpha2*Sconv2;
f=m_water[t]*(h_innlet-h_outlet)*1000;
e=density_water*Cp_water*Vol_w/Inc_t+density_steel*Cp_steel*vol_steel_inside/(L*Inc_t);
a=d+e+c;

T[i][j][t]=(d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+f+e*T[i][j][t-1])/a;
}

if(i==N+M+2)
{
Sconv2=2*pi*ri[i]*Inc_z*0.5;
Se=2*pi*re[i]*Inc_z*0.5;
Sz_steel=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=Sz_steel*Inc_z*0.5;

d=tc_steel*Se/Inc_steel;
b=alpha2*Sconv2;
c=tc_steel*Sz_steel/Inc_z;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}
```

```
if((i>N+M+2)&&(i<N+M+R+2))
{
Se=2*pi*re[i]*Inc_z*0.5;
Sw=2*pi*rw[i]*Inc_z*0.5;
Sz_steel=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_steel=Sz_steel*Inc_z*0.5;

b=tc_steel*Sw/Inc_steel;
d=tc_steel*Se/Inc_steel;
c=tc_steel*Sz_steel/Inc_z;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+R+2)
{
Se=2*pi*re[i]*Inc_z*0.5;
Sw=2*pi*rw[i]*Inc_z*0.5;
Sz_steel=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PU=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z*0.5;
Vol_PU=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z*0.5;

b=tc_steel*Sw/Inc_steel;
d=tc_PU*Se/Inc_PU;
c=tc_steel*Sz_steel/Inc_z+tc_PU*Sz_PU/Inc_z;
e=(density_steel*Cp_steel*Vol_steel/Inc_t+density_PU*Cp_PU*Vol_PU/Inc_t);
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
```

```
}

if((i>N+M+R+2)&&(i<w))
{
Se=2*pi*re[i]*Inc_z*0.5;
Sw=2*pi*rw[i]*Inc_z*0.5;
Sz_PU=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z*0.5;

b=tc_PU*Sw/Inc_PU;
d=tc_PU*Se/Inc_PU;
c=tc_PU*Sz_PU/Inc_z;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==w)
{
if(t==1000)
{
a=10;
}
Sconv3=2*pi*ri[i]*Inc_z*0.5;
Sconv4=pi*ri[i]*ri[i];
Sw=2*pi*rw[i]*Inc_z*0.5;
Sz_PU=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z*0.5;

Tfilm=273.15+((T_air+Ta[i][j][t])/2); /*Temperatura de l'aire amb graus kelvin*/
```

```
beta=0.0169811-0.0000855186*Tfilm+0.000000130714*Tfilm*Tfilm;
density_air=8.2131-0.0649*Tfilm+0.0002*Tfilm*Tfilm-0.0000002*Tfilm*Tfilm*Tfilm;
visc_air=-0.0000004+0.00000008*Tfilm-0.00000000005*Tfilm*Tfilm;
Pr=0.8073-0.0004*Tfilm+0.0000002*Tfilm*Tfilm;
tc_air=-0.0003+0.0001*Tfilm-0.00000004*Tfilm*Tfilm;
Inc_tita=fabs(T_air-Ta[i][j][t]);
q=g*beta*pow(density_air,2)*(Inc_tita);
o=pow(Inc_z*0.5,3)/pow(visc_air,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha3=Nu*tc_air/(Inc_z*0.5);

q=g*beta*pow(density_air,2)*(Inc_tita);
o=pow(diameter_tank,3)/pow(visc_air,2);
Gr=o*q;
F=Gr*Pr;
Nu=0.54*pow(F,0.25);
alpha4=Nu*tc_air/(diameter_tank);

b=tc_PU*Sw/Inc_PU;
d=alpha3*Sconv3+alpha4*Sconv4;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
c=tc_PU*Sz_PU/Inc_z;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*T_air+e*T[i][j][t-1])/a;
}
}/**tanca el for i ++**/
```

```
		}/*tanca el if j*/

/*________________________________________________________________________________*/
	if((j>0)&&(j<LPCM))
	{

		for(i=0;i<=w;i++)
		{
		if(i==N+M+1)
		{
		Tfilm=(Ta[i][j][t]+Ta[i+1][j][t])/2;

		beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
		density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
		visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
		Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
		tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
		Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
		q=g*beta*pow(density_water,2)*(Inc_tita);
		o=pow(Inc_z,3)/pow(visco,2);
		Gr=o*q;
		F=Gr*Pr;
		G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
		Nu=0.8*pow(F,0.25)*G;
		alpha2=Nu*tc_water/(Inc_z);
		Cp_water=4171.33+0.301902*Ta[i][j][t]-0.0068101*Ta[i][j][t]*Ta[i][j][t]+0.0000664071*Ta[i][j][t]*Ta[i][j][t]*Ta[i][j][t];

		h_innlet=0.153035+4.18555*Twater_inlet;
```

```
h_outlet=0.153035+4.18555*Ta[i][j][t];

Sconv2=2*pi*(ri[i+1])*Inc_z;
Vol_w=Vol_tank/L;
Sz=pi*(ri[i+1])*(ri[i+1]);

c=tc_water*Sz/Inc_z;
d=alpha2*Sconv2;
f=m_water[t]*(h_innlet-h_outlet)*1000;
e=density_water*Cp_water*Vol_w/Inc_t+density_steel*Cp_steel*vol_steel_inside/(L*Inc_t);
a=d+e+2*c;

T[i][j][t]=(d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+f+e*T[i][j][t-1])/a;
}

if(i==N+M+2)
{
Sconv2=2*pi*ri[i]*Inc_z;
Se=2*pi*re[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=Sz_steel*Inc_z;

d=tc_steel*Se/Inc_steel;
b=alpha2*Sconv2;
c=tc_steel*Sz_steel/Inc_z;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}
```

```
if((i>N+M+2)&&(i<N+M+R+2))
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_steel=Sz_steel*Inc_z;

b=tc_steel*Sw/Inc_steel;
d=tc_steel*Se/Inc_steel;
c=tc_steel*Sz_steel/Inc_z;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+R+2)
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PU=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PU=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;

b=tc_steel*Sw/Inc_steel;
d=tc_PU*Se/Inc_PU;
c=tc_steel*Sz_steel/Inc_z+tc_PU*Sz_PU/Inc_z;
e=(density_steel*Cp_steel*Vol_steel/Inc_t+density_PU*Cp_PU*Vol_PU/Inc_t);
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
```

```
}

if((i>N+M+R+2)&&(i<w))
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z;

b=tc_PU*Sw/Inc_PU;
d=tc_PU*Se/Inc_PU;
c=tc_PU*Sz_PU/Inc_z;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==w)
{
if(t==1000)
{
a=10;
}
Sconv3=2*pi*ri[i]*Inc_z;
Sconv4=pi*ri[i]*ri[i];
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z;

Tfilm=273.15+((T_air+Ta[i][j][t])/2); /*Temperatura de l'aire amb graus kelvin*/
```

```
beta=0.0169811-0.0000855186*Tfilm+0.000000130714*Tfilm*Tfilm;
density_air=8.2131-0.0649*Tfilm+0.0002*Tfilm*Tfilm-0.0000002*Tfilm*Tfilm*Tfilm;
visc_air=-0.0000004+0.00000008*Tfilm-0.00000000005*Tfilm*Tfilm;
Pr=0.8073-0.0004*Tfilm+0.0000002*Tfilm*Tfilm;
tc_air=-0.0003+0.0001*Tfilm-0.00000004*Tfilm*Tfilm;
Inc_tita=fabs(T_air-Ta[i][j][t]);
q=g*beta*pow(density_air,2)*(Inc_tita);
o=pow(Inc_z,3)/pow(visc_air,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha3=Nu*tc_air/(Inc_z);

q=g*beta*pow(density_air,2)*(Inc_tita);
o=pow(diameter_tank,3)/pow(visc_air,2);
Gr=o*q;
F=Gr*Pr;
Nu=0.54*pow(F,0.25);
alpha4=Nu*tc_air/(diameter_tank);

b=tc_PU*Sw/Inc_PU;
d=alpha3*Sconv3;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
c=tc_PU*Sz_PU/Inc_z;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*T_air+e*T[i][j][t-1])/a;
}
}/**tanca el for i ++**/
```

```
    }/*tanca el if j*/
/*________________________________________________________________________*/

    if(j==LPCM)
    {
    for(i=0;i<=w;i++)
    {
    if(i==0)
    {
    Se=2*pi*re[i]*(Inc_z);
    Sz=pi*re[i]*re[i];
    Vol=Sz*(Inc_z);
    k=Ta[i][j][t];
    h=Ta[i][j][t]-k;
    tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
    density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

    k=Ta[i][j][t]*10;
    h=Ta[i][j][t]*10-k;
    Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

    d=tc_PCM_i*Se/Inc_PCM;
    e=density_PCM_i*Cp_i*Vol/Inc_t;
    c=tc_PCM_i*Sz/Inc_z;
    a=d+e+c;
    T[i][j][t]=(d*Ta[i+1][j][t]+e*T[i][j][t-1]+c*Ta[i][j+1][t])/a;
    }

    if((i>0)&&(i<N))
    {
```

```
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol=Sz*(Inc_z);
k=Ta[i][j][t];
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

k=Ta[i][j][t]*10;
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

b=tc_PCM_i*Sw/Inc_PCM;
d=tc_PCM_i*Se/Inc_PCM;
c=tc_PCM_i*Sz/Inc_z;
e=density_PCM_i*Cp_i*Vol/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N)
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PCM=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PVC=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_PCM=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PVC=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;
```

```
k=Ta[i][j][t];
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

k=Ta[i][j][t]*10;
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

b=tc_PCM_i*Sw/Inc_PCM;
d=tc_PVC*Se/Inc_PVC;
c=(tc_PCM_i*Sz_PCM+tc_PVC*Sz_PVC)/Inc_z;
e=(density_PCM_i*Cp_i*Vol_PCM/Inc_t+density_PVC*Cp_PVC*Vol_PVC/Inc_t);
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}
/**-----------------**/

if((i>N)&&(i<N+M))
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PVC=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PVC=Sz_PVC*Inc_z;

b=tc_PVC*Sw/Inc_PVC;
d=tc_PVC*Se/Inc_PVC;
c=tc_PVC*Sz_PVC/Inc_z;
e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
a=b+d+e+c;
```

```
        T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
        }

        if(i==N+M)
        {
        Sconv1=2*pi*ri[i]*(Inc_z);
        Sw=2*pi*rw[i]*(Inc_z);
        Sz_PVC=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
        Vol_PVC=Sz_PVC*Inc_z;

        Tfilm=(Ta[i+1][j][t]+Ta[i][j][t])/2;

        beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
        density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
        visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
        Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
        tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
        Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
        q=g*beta*pow(density_water,2)*(Inc_tita);
        o=pow(Inc_z,3)/pow(visco,2);
        Gr=o*q;
        F=Gr*Pr;
        G=Pr/(1+1.05*Pr);
        /*Nu=0.686*pow(F,0.25)*pow(G,0.25);*/
        /*Nu=0.686*pow(F,0.25)*pow(G,0.25)+0.52*Inc_z/diameter_tube;*/
        Nu=0.59*pow(F,0.25);
        alpha1=Nu*tc_water/(Inc_z);
        /**alpha1[t]=150;**/
```

```
b=tc_PVC*Sw/Inc_PVC;
d=alpha1*Sconv1;
c=tc_PVC*Sz_PVC/Inc_z;
e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+1)
{
Tfilm=(Ta[i][j][t]+Ta[i+1][j][t])/2;

beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
q=g*beta*pow(density_water,2)*(Inc_tita);
o=pow(Inc_z,3)/pow(visco,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha2=Nu*tc_water/(Inc_z);
Cp_water=4171.33+0.301902*Ta[i][j][t]-0.0068101*Ta[i][j][t]*Ta[i][j][t]+0.0000664071*Ta[i][j][t]*Ta[i][j][t]*Ta[i][j][t];
```

```
h_innlet=0.153035+4.18555*Ta[i][j-1][t];
h_outlet=0.153035+4.18555*Ta[i][j][t];

Sconv1=n_tubes*2*pi*(ri[i-1])*(Inc_z);
Sconv2=2*pi*(ri[i+1])*Inc_z;
Vol_w=Vol_tank/L;
Sz=2*pi*(ri[i+1])*(ri[i+1]);

b=alpha1*Sconv1;
d=alpha2*Sconv2;
f=m_water[t]*(h_innlet-h_outlet)*1000;
c=tc_water*Sz/Inc_z;
e=density_water*Cp_water*Vol_w/Inc_t+density_steel*Cp_steel*vol_steel_inside/(L*Inc_t);
a=b+d+e+2*c;

T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+f+e*T[i][j][t-1])/a;
}

if(i==N+M+2)
{
Sconv2=2*pi*ri[i]*Inc_z;
Se=2*pi*re[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=Sz_steel*Inc_z;

d=tc_steel*Se/Inc_steel;
b=alpha2*Sconv2;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
c=tc_steel*Sz_steel/Inc_z;
a=b+d+e+2*c;
```

```
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if((i>N+M+2)&&(i<N+M+R+2))
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_steel=Sz_steel*Inc_z;

b=tc_steel*Sw/Inc_steel;
d=tc_steel*Se/Inc_steel;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
c=tc_steel*Sz_steel/Inc_z;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+R+2)
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PU=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PU=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;

b=tc_steel*Sw/Inc_steel;
d=tc_PU*Se/Inc_PU;
c=(tc_PU*Sz_PU+tc_steel*Sz_steel)/Inc_z;
```

```
e=(density_steel*Cp_steel*Vol_steel/Inc_t+density_PU*Cp_PU*Vol_PU/Inc_t);
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if((i>N+M+R+2)&&(i<w))
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z;

b=tc_PU*Sw/Inc_PU;
d=tc_PU*Se/Inc_PU;
c=(tc_PU*Sz_PU)/Inc_z;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if(i==w)
{
if(t==1000)
{
a=10;
}
Sconv3=2*pi*ri[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z;
```

```
Tfilm=273.15+((T_air+Ta[i][j][t])/2); /*Temperatura de l'aire amb graus kelvin*/

beta=0.0169811-0.0000855186*Tfilm+0.000000130714*Tfilm*Tfilm;
density_air=8.2131-0.0649*Tfilm+0.0002*Tfilm*Tfilm-0.0000002*Tfilm*Tfilm*Tfilm;
visc_air=-0.0000004+0.00000008*Tfilm-0.00000000005*Tfilm*Tfilm;
Pr=0.8073-0.0004*Tfilm+0.0000002*Tfilm*Tfilm;
tc_air=-0.0003+0.0001*Tfilm-0.00000004*Tfilm*Tfilm;
Inc_tita=fabs(T_air-Ta[i][j][t]);
q=g*beta*pow(density_air,2)*(Inc_tita);
o=pow(Inc_z,3)/pow(visc_air,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha3=Nu*tc_air/(Inc_z);

b=tc_PU*Sw/Inc_PU;
c=tc_PU*Sz_PU/Inc_z;
d=alpha3*Sconv3;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*T_air+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}
}/**tanca el for i ++**/
}/**tanca el if j ++**/
/*______________________________________________________________________________*/

if((j>LPCM)&&(j<L-1))
{
```

```
for(i=0;i<=w;i++)
{
if(i==0)
{
Se=2*pi*re[i]*(Inc_z);
Sz=pi*re[i]*re[i];
Vol=Sz*(Inc_z);
k=Ta[i][j][t];
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

k=Ta[i][j][t]*10;
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

d=tc_PCM_i*Se/Inc_PCM;
e=density_PCM_i*Cp_i*Vol/Inc_t;
c=tc_PCM_i*Sz/Inc_z;
a=d+e+2*c;
T[i][j][t]=(d*Ta[i+1][j][t]+e*T[i][j][t-1]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t])/a;
}

if((i>0)&&(i<N))
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol=Sz*(Inc_z);
k=Ta[i][j][t];
```

```
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

k=Ta[i][j][t]*10;
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

b=tc_PCM_i*Sw/Inc_PCM;
d=tc_PCM_i*Se/Inc_PCM;
c=tc_PCM_i*Sz/Inc_z;
e=density_PCM_i*Cp_i*Vol/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N)
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PCM=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PVC=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_PCM=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PVC=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;

k=Ta[i][j][t];
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;
```

```
k=Ta[i][j][t]*10;
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

b=tc_PCM_i*Sw/Inc_PCM;
d=tc_PVC*Se/Inc_PVC;
c=(tc_PCM_i*Sz_PCM+tc_PVC*Sz_PVC)/Inc_z;
e=(density_PCM_i*Cp_i*Vol_PCM/Inc_t+density_PVC*Cp_PVC*Vol_PVC/Inc_t);
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}
/**-----------------**/

if((i>N)&&(i<N+M))
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PVC=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PVC=Sz_PVC*Inc_z;

b=tc_PVC*Sw/Inc_PVC;
d=tc_PVC*Se/Inc_PVC;
c=tc_PVC*Sz_PVC/Inc_z;
e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N+M)
{
```

```
Sconv1=2*pi*ri[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PVC=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PVC=Sz_PVC*Inc_z;

Tfilm=(Ta[i+1][j][t]+Ta[i][j][t])/2;

beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
q=g*beta*pow(density_water,2)*(Inc_tita);
o=pow(Inc_z,3)/pow(visco,2);
Gr=o*q;
F=Gr*Pr;
G=Pr/(1+1.05*Pr);
/*Nu=0.686*pow(F,0.25)*pow(G,0.25);*/
/*Nu=0.686*pow(F,0.25)*pow(G,0.25)+0.52*Inc_z/diameter_tube;*/
Nu=0.59*pow(F,0.25);
alpha1=Nu*tc_water/(Inc_z);
/**alpha1[t]=150;**/

b=tc_PVC*Sw/Inc_PVC;
d=alpha1*Sconv1;
c=tc_PVC*Sz_PVC/Inc_z;
e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
```

```
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+1)
{
Tfilm=(Ta[i][j][t]+Ta[i+1][j][t])/2;

beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
q=g*beta*pow(density_water,2)*(Inc_tita);
o=pow(Inc_z,3)/pow(visco,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha2=Nu*tc_water/(Inc_z);
Cp_water=4171.33+0.301902*Ta[i][j][t]-0.0068101*Ta[i][j][t]*Ta[i][j][t]+0.0000664071*Ta[i][j][t]*Ta[i][j][t]*Ta[i][j][t];

h_innlet=0.153035+4.18555*Ta[i][j-1][t];
h_outlet=0.153035+4.18555*Ta[i][j][t];

Sconv1=n_tubes*2*pi*(ri[i-1])*(Inc_z);
Sconv2=2*pi*(ri[i+1])*Inc_z;
```

```
Vol_w=Vol_tank/L;
Sz=2*pi*(ri[i+1])*(ri[i+1]);

b=alpha1*Sconv1;
d=alpha2*Sconv2;
f=m_water[t]*(h_innlet-h_outlet)*1000;
c=tc_water*Sz/Inc_z;
e=density_water*Cp_water*Vol_w/Inc_t+density_steel*Cp_steel*vol_steel_inside/(L*Inc_t);
a=b+d+e+2*c;

T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+f+e*T[i][j][t-1])/a;
}

if(i==N+M+2)
{
Sconv2=2*pi*ri[i]*Inc_z;
Se=2*pi*re[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=Sz_steel*Inc_z;

d=tc_steel*Se/Inc_steel;
b=alpha2*Sconv2;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
c=tc_steel*Sz_steel/Inc_z;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if((i>N+M+2)&&(i<N+M+R+2))
{
```

```
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_steel=Sz_steel*Inc_z;

b=tc_steel*Sw/Inc_steel;
d=tc_steel*Se/Inc_steel;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
c=tc_steel*Sz_steel/Inc_z;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+R+2)
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PU=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PU=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;

b=tc_steel*Sw/Inc_steel;
d=tc_PU*Se/Inc_PU;
c=(tc_PU*Sz_PU+tc_steel*Sz_steel)/Inc_z;
e=(density_steel*Cp_steel*Vol_steel/Inc_t+density_PU*Cp_PU*Vol_PU/Inc_t);
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}
```

```
if((i>N+M+R+2)&&(i<w))
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z;

b=tc_PU*Sw/Inc_PU;
d=tc_PU*Se/Inc_PU;
c=(tc_PU*Sz_PU)/Inc_z;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e+2*c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if(i==w)
{
if(t==1000)
{
a=10;
}
Sconv3=2*pi*ri[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z;

Tfilm=273.15+((T_air+Ta[i][j][t])/2); /*Temperatura de l'aire amb graus kelvin*/

beta=0.0169811-0.0000855186*Tfilm+0.000000130714*Tfilm*Tfilm;
density_air=8.2131-0.0649*Tfilm+0.0002*Tfilm*Tfilm-0.0000002*Tfilm*Tfilm*Tfilm;
```

```
        visc_air=-0.0000004+0.00000008*Tfilm-0.00000000005*Tfilm*Tfilm;
        Pr=0.8073-0.0004*Tfilm+0.0000002*Tfilm*Tfilm;
        tc_air=-0.0003+0.0001*Tfilm-0.00000004*Tfilm*Tfilm;
        Inc_tita=fabs(T_air-Ta[i][j][t]);
        q=g*beta*pow(density_air,2)*(Inc_tita);
        o=pow(Inc_z,3)/pow(visc_air,2);
        Gr=o*q;
        F=Gr*Pr;
        G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
        Nu=0.8*pow(F,0.25)*G;
        alpha3=Nu*tc_air/(Inc_z);

        b=tc_PU*Sw/Inc_PU;
        c=tc_PU*Sz_PU/Inc_z;
        d=alpha3*Sconv3;
        e=density_PU*Cp_PU*Vol_PU/Inc_t;
        a=b+d+e+2*c;
        T[i][j][t]=(b*Ta[i-1][j][t]+d*T_air+c*Ta[i][j+1][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
        }
        }/**tanca el for i ++**/
        }/**tanca el if j ++**/
/*________________________________________________________________________*/

        if(j==L-1)
        {
        for(i=0;i<=w;i++)
        {
        if(i==0)
        {
        Se=2*pi*re[i]*(Inc_z);
```

```
Sz=pi*re[i]*re[i];
Vol=Sz*(Inc_z);
k=Ta[i][j][t];
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

k=Ta[i][j][t]*10;
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

d=tc_PCM_i*Se/Inc_PCM;
e=density_PCM_i*Cp_i*Vol/Inc_t;
c=tc_PCM_i*Sz/Inc_z;
a=d+e+c;
T[i][j][t]=(d*Ta[i+1][j][t]+e*T[i][j][t-1]+c*Ta[i][j-1][t])/a;
}

if((i>0)&&(i<N))
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol=Sz*(Inc_z);
k=Ta[i][j][t];
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

k=Ta[i][j][t]*10;
```

```
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

b=tc_PCM_i*Sw/Inc_PCM;
d=tc_PCM_i*Se/Inc_PCM;
c=tc_PCM_i*Sz/Inc_z;
e=density_PCM_i*Cp_i*Vol/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N)
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PCM=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PVC=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_PCM=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PVC=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;

k=Ta[i][j][t];
h=Ta[i][j][t]-k;
tc_PCM_i=tc_PCM[k]+(tc_PCM[k+1]-tc_PCM[k])*h;
density_PCM_i=density_PCM[k]+(density_PCM[k+1]-density_PCM[k])*h;

k=Ta[i][j][t]*10;
h=Ta[i][j][t]*10-k;
Cp_i=Cp_PCM[k]+(Cp_PCM[k+1]-Cp_PCM[k])*h;

b=tc_PCM_i*Sw/Inc_PCM;
```

```
d=tc_PVC*Se/Inc_PVC;
c=(tc_PCM_i*Sz_PCM+tc_PVC*Sz_PVC)/Inc_z;
e=(density_PCM_i*Cp_i*Vol_PCM/Inc_t+density_PVC*Cp_PVC*Vol_PVC/Inc_t);
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}
/**-----------------**/

if((i>N)&&(i<N+M))
{
Se=2*pi*re[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PVC=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_PVC=Sz_PVC*Inc_z;

b=tc_PVC*Sw/Inc_PVC;
d=tc_PVC*Se/Inc_PVC;
c=tc_PVC*Sz_PVC/Inc_z;
e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N+M)
{
Sconv1=2*pi*ri[i]*(Inc_z);
Sw=2*pi*rw[i]*(Inc_z);
Sz_PVC=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PVC=Sz_PVC*Inc_z;
```

```
Tfilm=(Ta[i+1][j][t]+Ta[i][j][t])/2;

beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
q=g*beta*pow(density_water,2)*(Inc_tita);
o=pow(Inc_z,3)/pow(visco,2);
Gr=o*q;
F=Gr*Pr;
G=Pr/(1+1.05*Pr);
/*Nu=0.686*pow(F,0.25)*pow(G,0.25);*/
/*Nu=0.686*pow(F,0.25)*pow(G,0.25)+0.52*Inc_z/diameter_tube;*/
Nu=0.59*pow(F,0.25);
alpha1=Nu*tc_water/(Inc_z);
/**alpha1[t]=150;**/

b=tc_PVC*Sw/Inc_PVC;
d=alpha1*Sconv1;
c=tc_PVC*Sz_PVC/Inc_z;
e=density_PVC*Cp_PVC*Vol_PVC/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+1)
```

```
{
Tfilm=(Ta[i][j][t]+Ta[i+1][j][t])/2;

beta=0.000212527+0.00000294849*Tfilm+0.0000000150068*Tfilm*Tfilm;
density_water=1004.14-0.174562*Tfilm-0.00256762*Tfilm*Tfilm;
visco=0.0017839-0.0000565435*Tfilm+0.00000106222*Tfilm*Tfilm-
0.0000000105683*Tfilm*Tfilm*Tfilm+0.00000000004154*Tfilm*Tfilm*Tfilm*Tfilm;
Pr=13.0186-0.309814*Tfilm+0.0029781*Tfilm*Tfilm-
0.0000121781*Tfilm*Tfilm*Tfilm+0.0000000176967*Tfilm*Tfilm*Tfilm*Tfilm;
tc_water=0.556287+0.00207842*Tfilm-0.00000825256*Tfilm*Tfilm+0.000000000782952*Tfilm*Tfilm*Tfilm;
Inc_tita=fabs(Ta[i+1][j][t]-Ta[i][j][t]);
q=g*beta*pow(density_water,2)*(Inc_tita);
o=pow(Inc_z,3)/pow(visco,2);
Gr=o*q;
F=Gr*Pr;
G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
Nu=0.8*pow(F,0.25)*G;
alpha2=Nu*tc_water/(Inc_z);
Cp_water=4171.33+0.301902*Ta[i][j][t]-0.0068101*Ta[i][j][t]*Ta[i][j][t]+0.0000664071*Ta[i][j][t]*Ta[i][j][t]*Ta[i][j][t];

h_innlet=0.153035+4.18555*Ta[i][j-1][t];
h_outlet=0.153035+4.18555*Ta[i][j][t];

Sconv1=n_tubes*2*pi*(ri[i-1])*(Inc_z);
Sconv2=2*pi*(ri[i+1])*Inc_z;
Vol_w=Vol_tank/L;
Sz=2*pi*(ri[i+1])*(ri[i+1]);

b=alpha1*Sconv1;
d=alpha2*Sconv2;
```

```
f=m_water[t]*(h_innlet-h_outlet)*1000;
c=tc_water*Sz/Inc_z;
e=density_water*Cp_water*Vol_w/Inc_t+density_steel*Cp_steel*vol_steel_inside/(L*Inc_t);
a=b+d+e+c;

T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+f+e*T[i][j][t-1])/a;
}

if(i==N+M+2)
{
Sconv2=2*pi*ri[i]*Inc_z;
Se=2*pi*re[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=Sz_steel*Inc_z;

d=tc_steel*Se/Inc_steel;
b=alpha2*Sconv2;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
c=tc_steel*Sz_steel/Inc_z;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+c*Ta[i][j-1][t]+d*Ta[i+1][j][t]+e*T[i][j][t-1])/a;
}

if((i>N+M+2)&&(i<N+M+R+2))
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(re[i]*re[i]-rw[i]*rw[i]);
Vol_steel=Sz_steel*Inc_z;
```

```
b=tc_steel*Sw/Inc_steel;
d=tc_steel*Se/Inc_steel;
e=density_steel*Cp_steel*Vol_steel/Inc_t;
c=tc_steel*Sz_steel/Inc_z;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if(i==N+M+R+2)
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_steel=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Sz_PU=pi*(re[i]*re[i]-ri[i]*ri[i]);
Vol_steel=(ri[i]*ri[i]-rw[i]*rw[i])*pi*Inc_z;
Vol_PU=(re[i]*re[i]-ri[i]*ri[i])*pi*Inc_z;

b=tc_steel*Sw/Inc_steel;
d=tc_PU*Se/Inc_PU;
c=(tc_PU*Sz_PU+tc_steel*Sz_steel)/Inc_z;
e=(density_steel*Cp_steel*Vol_steel/Inc_t+density_PU*Cp_PU*Vol_PU/Inc_t);
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if((i>N+M+R+2)&&(i<w))
{
Se=2*pi*re[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(re[i]*re[i]-rw[i]*rw[i]);
```

```
Vol_PU=Sz_PU*Inc_z;

b=tc_PU*Sw/Inc_PU;
d=tc_PU*Se/Inc_PU;
c=(tc_PU*Sz_PU)/Inc_z;
e=density_PU*Cp_PU*Vol_PU/Inc_t;
a=b+d+e+c;
T[i][j][t]=(b*Ta[i-1][j][t]+d*Ta[i+1][j][t]+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
}

if(i==w)
{
if(t==1000)
{
a=10;
}
Sconv3=2*pi*ri[i]*Inc_z;
Sw=2*pi*rw[i]*Inc_z;
Sz_PU=pi*(ri[i]*ri[i]-rw[i]*rw[i]);
Vol_PU=Sz_PU*Inc_z;

Tfilm=273.15+((T_air+Ta[i][j][t])/2); /*Temperatura de l'aire amb graus kelvin*/

beta=0.0169811-0.0000855186*Tfilm+0.000000130714*Tfilm*Tfilm;
density_air=8.2131-0.0649*Tfilm+0.0002*Tfilm*Tfilm-0.0000002*Tfilm*Tfilm*Tfilm;
visc_air=-0.0000004+0.00000008*Tfilm-0.00000000005*Tfilm*Tfilm;
Pr=0.8073-0.0004*Tfilm+0.0000002*Tfilm*Tfilm;
tc_air=-0.0003+0.0001*Tfilm-0.00000004*Tfilm*Tfilm;
Inc_tita=fabs(T_air-Ta[i][j][t]);
q=g*beta*pow(density_air,2)*(Inc_tita);
```

```
            o=pow(Inc_z,3)/pow(visc_air,2);
            Gr=o*q;
            F=Gr*Pr;
            G=pow(1+pow(1+1/pow(Pr,0.5),2),-0.25);
            Nu=0.8*pow(F,0.25)*G;
            alpha3=Nu*tc_air/(Inc_z);

            b=tc_PU*Sw/Inc_PU;
            c=tc_PU*Sz_PU/Inc_z;
            d=alpha3*Sconv3;
            e=density_PU*Cp_PU*Vol_PU/Inc_t;
            a=b+d+e+c;
            T[i][j][t]=(b*Ta[i-1][j][t]+d*T_air+c*Ta[i][j-1][t]+e*T[i][j][t-1])/a;
            }
            }/**tanca el for i ++**/
            }/**tanca el if j ++**/
/*________________________________________________________________________________*/


}/**tanca el for j ++**/



/*Error calculation*/
for(j=0;j<L;j++)
{
   for (i=0;i<=w;i++)
   {
   error=fabs(T[i][j][t]-Ta[i][j][t]);
      if(error>errort)
```

```
        errort=error;
        else
        errort=errort;
    }
}
if(errort>max_error)
{
for(j=0;j<L;j++)
{
for (i=0;i<=w;i++)
    {

    Ta[i][j][t]=T[i][j][t]*rel+Ta[i][j][t]*(1-rel);
    }
}
}
if(errort<max_error)break;
}

if(m_water[t]>0)
{
time_on=time_on+Inc_t;
}

thermal_energy[t]=m_water[t]*(4.18555*T[N+M+1][L-1][t]-4.18555*T_confort);
}


/**---------------------------------------------------------------------------**/
```

```
/**Print results**/

fprintf(trans, "time, T0_PCM, Tmid_PCM, Tout_PCM, TPVCext, Taigua0, Taigua10, Taigua20, Taigua30, Taigua40, Taigua50, Taigua60,
Tsteelint, Twallout, mfr, thermal_energy, time_on %-2.5f,\n", time_on);
t=0;
while(t<=Total_time)
{
time=Inc_t*t/60;
fprintf(trans, "%-2.5f,",time);
j=69;
fprintf(trans, "%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.2f,%-2.5f, %-
2.8f",T[0][j][t],T[5][j][t], T[10][j][t], T[15][j][t], T[N+M+1][23][t], T[N+M+1][31][t], T[N+M+1][39][t], T[N+M+1][47][t],
T[N+M+1][55][t],T[N+M+1][62][t], T[N+M+1][69][t], T[17][j][t], T[28][j][t], m_water[t], thermal_energy[t]);
fprintf(trans, "\n");
t=t+1;
}
printf("finished");
getch();
}
```